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EVALUATION OF ALTERNATIVE SUBSTRATES ON GROWTH AND KEEPING QUALITY OF *Heliconia psittacorum* L. CUT FLOWERS

FELIX KORDZO AMEKUEDI

DEPARTMENT OF CROP SCIENCE



OCTOBER 2025

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BY

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(10935433)

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DEPARTMENT OF CROP SCIENCE

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DECLARATION

I hereby declare that, except for references to other peoples' work which have been duly acknowledged, this research work is the result of my own effort, and that it has neither in wholly or partially been submitted in this university or elsewhere for the award of a degree.

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ABSTRACT

This study evaluated the impact of alternative substrates on the growth and postharvest performance of *Heliconia psittacorum* L., with the aim of optimizing cultivation media and assessing the effects of sucrose-based preservatives on cut flower quality. Conducted over two periods, the research involved pot and vase-life experiments arranged in a randomized complete block design (RCBD) for six growth media: Decomposed Oil Palm Stems (DOS), Top Soil + Chicken Manure (TS + CM) (1:1), Top Soil + Coconut Fibre (TS + CF) (1:1), River Sand + Chicken Manure (RS + CM) (1:1), River Sand + Coconut Fibre (RS + CF) (1:1), and Clayey Soil (CS) as the control. Additionally, a completely randomized design (CRD) was used to test four sucrose treatments (0%, 10%, 15%, 20%) w/v in vase-life studies. Among the substrates, DOS supported the fastest sprouting (3.9–5.2 weeks), RS + CM resulted in the highest sprout density, TS + CF led to the earliest flowering (161.0 days), and TS + CM promoted superior vegetative growth. Substrate effects on biomass accumulation, stem girth, and chlorophyll content varied among the two growing periods under study. In vase-life trials, 0% sucrose (distilled water) consistently outperformed sucrose treatments in fresh weight retention, vase solution uptake, and flower longevity, particularly in the first experiment. Higher sucrose levels, especially at 20%, accelerated respiration rates, while moderate concentrations showed inconsistent effects on flower metabolism, with visual quality and physiological responses differing across experiments. The findings indicate that agricultural waste such as Top Soil + Chicken Manure can serve as effective cultivation media for higher vegetative growth of *Heliconia psittacorum* in Ghana, whereas 0% sucrose may be sufficient, and if there is a need to add sucrose, a 10% sucrose concentration will be sufficient for improving cut flower postharvest quality and cut flower longevity.

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DEDICATION

I dedicate this research work to my family.



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My greatest gratitude goes to the Almighty God, the giver of life and wisdom for His guidance, protection and direction that has made this research work a success. My heartfelt appreciation also goes to my supervisors, Dr. Naalamle Amissah and Dr. Daniel Brain Akakpo for their useful suggestions and constructive criticism that have made this work a success. Finally, I would like to thank Prof, Kwadwo Ofori whose useful suggestions also contributed to the success of this work, and to all my friends whose motivation and encouragement sustained me throughout this period of the work. Their loyalty and willingness are acknowledged here with deep gratitude.



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LIST OF ABBREVIATIONS

Abbreviation	Full Meaning
RH	Relative Humidity
°C	Degrees Celsius
LSD	Least Significant Difference
DAP	Days After Planting
DIP	Days In Preservation
mL	millilitre
USD	United States Dollar



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CHAPTER ONE

1.0 INTRODUCTION

Cut flower production has great potential in creating employment and generating foreign exchange earnings, and as such, the commercial production of cut flowers has been largely adopted by many developing countries as an economic growth strategy (Patel-Campillo, 2011). According to Hernández and Avitia-Rodríguez (2017), these developing countries are mainly found in Latin America and Central Africa.

In Ghana, small and marginal-scale growers are mostly responsible for traditional flower cultivation. For both the local and international markets, protected cultivation of flowers has received increased attention in recent years (Sapna *et al.*, 2019). Since then, floriculture has gained recognition as a lucrative career with a larger potential for profits per unit area.

In Ghana, where youth unemployment is higher than public numbers, floriculture is a growing industry that can provide self-employment if given the needed attention. However, compared to the largest flower growers in Africa, the nation's floriculture sector is still in its developing stage. According to the World Bank's World Integrated Trade Solution database, Ghana exported USD 1,995,400 worth of fresh cut flowers and buds in 2023, while Kenya's exports of the same category were valued at USD 660,847,750 (WITS, 2025).

The climate and other natural features of Ghana make it an ideal place for the production of several exotic varieties of flowers, such as *Heliconia* spp.(heliconia), *Hibiscus rosa-sinensis* (hibiscus), *Celosia argentea* (celosia), *Alpinia caribaea* (caribea), *Curcuma longa* (curcuma), and *Gladiolus hortulanus* (gladioli), which have all performed well in Ghana under natural conditions (Greenroot, 2020); hence there is opportunity to expand the regions under cultivation for these and other cultivars that have not yet been identified.

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Heliconias are among cut flowers regarded for their colourful and eye-catching inflorescences, which are frequently utilized in gardens, cut flower arrangements, and as potted plants. One of the prominent and widely cultivated species of heliconias is *psittacorum. Heliconia psittacorum* L. is a tropical plant species with a high ornamental potential (Henny *et al*., 2022). It is an herbaceous plant species that belongs to the *Heliconiaceae* family, which is distributed mostly in Colombia, Brazil, French Guiana, Surinam, Guyana, Trinidad, and Venezuela.

The height of the plant ranges between 0.5 m and 1.5 m tall. It performs well under full sun and partial canopy and prefers moist and well-drained soils which are rich in organic matter. According to Malakar *et al.* (2023), the plant species was introduced to the cut flower trade in recent decades as a result of its beauty and elegance.

The plant is known to exhibit an exotic shape and possess a very beautiful inflorescence (Henny et al., 2022). According to Costa *et al*. (2009), Heliconias are very beautiful tropical flowers and hence can increase profits in the worldwide cut flower industry. The authors further indicated that there is a large market for the plant species internationally due to its bright colours and durability of its inflorescence. Recent findings by Bañuelos-Hernandez *et al*. (2016) indicate that *Heliconia psittacorum* L. has a high economic potential as a result of its colours, diverse shapes, and long vase life. Aside from the ornamental relevance of the plant, it is effective in removing pollutants such as heavy metals and metalloids in both water and soil (Malakar and Biswas, 2022; Wiafe *et al*., 2022).

Cut flowers go through physiological changes after being taken from the plant, which causes fast degradation. Long-distance transportation is required for the export of cut flowers. Meanwhile, the quality of the flowers degrades with increasing distance and transit time. Cut flower life is frequently increased by using low storage temperatures and modified atmospheres (Poonsri, 2021).

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In recent years, there has been a growing interest in cultivating *Heliconia psittacorum* in Ghana, both for local markets and export. However, there are limited literature from Ghana regarding the growth, flowering, and vase life of this crop unlike countries such as Colombia and Ecuador, where stable climates support consistent flower quality (Pizano, 2005). Since climate variations significantly influence plant development and performance (Raza et al., 2019), adopting proper pre-harvest practices is essential to maintain high flower quality. Research has shown that both substrate and environmental conditions play key roles in seedling formation and flower production in Heliconia (Beckmann-Cavalcante et al., 2011). Omovbude et al. (2016) reported that mixing topsoil with coconut husk promoted vigorous growth, while a blend of river sand and coconut husk also proved effective. Antosh (2023) emphasized the importance of nutrient-rich, well-draining soil for successful cultivation. Coconut fibre is increasingly recognized as a sustainable substrate because of its high water-holding capacity, good aeration, low bulk density and ability to improve root development in ornamental crops (Berruti & Scariot, 2012). Likewise, poultry manure and decomposed organic residues such as oil palm waste contribute essential nutrients, improve soil structure and stimulate microbial activity, thereby supporting plant growth and flower production. Studies on ornamental crops including rose, caladium and other tropical flowers have demonstrated that agricultural wastes such as coconut fibre, composted manure and plant residues can successfully replace conventional substrates while improving vegetative growth, flowering and overall plant quality (Bustamante et al., 2008; Khan et al., 2017). Similarly, Santos et al. (2015) reported that mixtures containing coconut husk powder and organic manures produced vigorous and high-quality seedlings of *Heliconia psittacorum*. Coconut fibre substrates were also found to increase flower production and stem quality in cut-flower heliconias under soilless cultivation systems (Díaz et al., 2009).

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This provides an exciting opportunity for Ghana, where agricultural waste poses significant challenges. Along the coastal belt, large quantities of coconut husks are often discarded as waste, accumulated after coconut harvesting. Similarly, in the Eastern and Western Regions, oil palm stems are typically burned after tree felling, contributing to environmental pollution. Poultry farmers across the country also struggle with the disposal of excess droppings. These biomass materials, if repurposed, could serve as eco-friendly, cost-effective substrates for Heliconia production. A local grower near the Dawhenya Irrigation Project has already begun experimenting with open-field cultivation on clayey Akuse series soil, despite its poor drainage and compaction issues (Ghana Districts, 2017). Leveraging local agricultural by-products like coconut husk, decomposed oil palm stems and poultry manure may not only address waste management problems but also enhance Heliconia growth and flowering. The utilization of these organic residues in floriculture also aligns with sustainable agricultural practices aimed at reducing environmental pollution and dependence on expensive imported substrates.

Beyond cultivation, maintaining flower quality postharvest is crucial for consumer satisfaction and commercial viability. Cut flowers are metabolically active and can deteriorate rapidly if not properly handled. Factors such as water balance, nutrition, ethylene sensitivity, and microbial presence all influence vase life (Vehniwal & Abbey, 2019). With Ghana's warm climate and inconsistent cold chain infrastructure, exploring natural and accessible methods to extend freshness is essential. Recent studies support the use of natural preservatives like sucrose and fruit extracts, which help sustain respiration and prolong flower life by replenishing carbohydrate reserves (Vehniwal & Abbey, 2019; Borghi & Fernie, 2017). In flower marketing, sugars play key roles in extending the vase life of cut flowers. Sucrose supplies respiratory substrates vital for flower metabolism, maintains osmotic regulation, sustains stem turgor and delays senescence. Costa et al. (2015) reported that pre-treatments of H. wagneriana with 10% and 20% sucrose solution improved postharvest longevity up to 18

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days. Carrera-Alvarado and Baltazar-Bernal (2021) also reported that pulsing Heliconia 'Tropics' with 10% sucrose improved floral opening, reduced fresh-weight loss, increased water uptake and extended vase life. Evaluating a sucrose concentration range of 0%, 10%, 15%, and 20% (w/v) is therefore aimed at maximizing vase life as well as improving flower quality.

This research aims not only to optimize the use of Ghana's agricultural residues as growth media but also to determine the most suitable substrate for reducing the biochemical activities that accelerate the deterioration of *Heliconia psittacorum* L. cut flowers. In doing so, it contributes to both sustainable agriculture and the development of a viable floriculture industry in Ghana

The main objective of the research was to evaluate the effects of different substrates on the growth and keeping quality of *Heliconia psittacorum* L.

The research also addressed the following specific objectives to:

1) determine the effect of substrate on growth and flowering of *Heliconia psittacorum*
2) determine the variations in the appearance of cut flower stems in different vase solutions, and
3) determine the vase-life of cut Heliconia flowers in varying preservative solutions.

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CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This section thoroughly explains the plant, focusing on its taxonomy, botany, physiological traits, and kinds, as well as its origin and distribution. Furthermore, a thorough discussion of pre- and post-harvest cultural activities and climate and environmental needs has been conducted.

2.2 Origin and Distribution of *Heliconia* species

Heliconias are tropical perennial herbaceous plants with brightly-coloured flowering bracts. Heliconias, named after Mt. Helicon (the dwelling place of the ancient Greek god), look similar to bananas (Maria *et al*., 2014). The majority of *Heliconia* species originated from tropical America, but some are from the Pacific Islands and Indonesia (Mahr, 2017). They can be identified by their lack of banana-like fruit and the fact that their leaves grow directly from the ground, rather than an upright trunk (Kapler, 2003).

Heliconias are often used as decorative flowers, particularly in areas where they cannot be produced in gardens (Maria *et al*., 2014). Owusu (2013), further indicated that *Heliconia psittacorum* is propagated in the floral industry as a cut flower as well as a landscape plant used for indoor and outdoor beautification.

2.3 Taxonomy of *Heliconia* species

Heliconia psittacorum L. is found within the Heliconia genus and is characterized by its high ornamental potential in addition to its genetic variability (Malakar and Biswas, 2022). The current understanding of Heliconia taxonomy reveals a complex and diverse genus, comprising approximately 380 species, primarily distributed in tropical America (Trejo-Téllez, 2018). The

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classification has evolved since Linnaeus established the genus in 1771, with ongoing debates regarding species identification due to morphological similarities and hybridization. According to Trejo-Téllezm (2018), there is a need for genetic techniques, such as chromosome counting and fluorescence in situ hybridization, to clarify taxonomic relationships and resolve synonyms.

The high degree of endemism in regions like Colombia highlights the need for conservation efforts to maintain genetic diversity. The current state of taxonomy in Heliconia is key to horticulture, where accurate species identification is crucial for effective cultivation and pest management. Despite advancements, challenges remain in Heliconia classification, particularly with the potential for misidentification affecting agricultural practices and market dynamics (Castro *et al*., 2007).

2.4 Botany of *Heliconia* species

Heliconias are a monophyletic genus of about 380 species, characterized by showy inflorescences, similar foliage to bananas, and notable self-incompatibility in some Central American populations (Malakar and Biswas, 2022). Heliconias are characterized by their vibrant inflorescences, which consist of modified leaves called bracts that create microhabitats for various insects and invertebrates (Méndez *et al*., 2024).

According to Ortiz-Curiel *et al*. (2023), Heliconia scarlet features red, brilliant bracts with revolute-involute margins, characterized by stable morphological traits suitable for cut flower and gardening applications under 30% shade. Santhosh *et al.* (2018) also reported that heliconia plants are characterized by their attractive foliage and brilliant flower spikes, featuring colorful bracts that subtend the flowers, exhibiting high natural variability in shape, size, and growth habit. The height of a typical Heliconia species ranges between 2 to 15 feet. Variations occur among the different species of heliconia; for instance, *Heliconia berguidoi* features pink

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flowers, a glabrous petiole with a woolly base, a long peduncle, and a staminode with a cuspidate apex, distinguishing it from similar species (Flores *et al*, 2017).

There exists a diverse array of species and cultivars within the genus *Heliconia psittacorum.* Among these species are the Giant Lobster Claw (*H. caribea*), the Hanging Lobster Claw (*H. rostrate*), and the Small Lobster Claw (*H. stricta*). Predominantly, these plants exhibit large foliar structures, frequently characterized by elongated petioles and prominent inflorescences, typically adorned with one or more vividly colored bracts. The majority of Heliconia species are highly adapted to the humid lowland tropical environments. These plants are relatively straightforward to cultivate and yield a spectacular display of chromatic variation. Numerous cultivars are noted for their enduring floral characteristics, rendering them exemplary candidates for cut flower arrangements (McConnell and Cruz, 2001).

2.5 Types of Heliconia species

The genus *Heliconia* encompasses a diverse array of species that are esteemed for their ornamental traits. The *Heliconia* species thrive mostly in warm, moist environments, particularly in the Americas. Among the most distinguished species are *Heliconia rostrata,* which is renowned for its strikingly dramatic hanging inflorescences, and *Heliconia bihai,* characterized by its erect bracts and frequent utilization in floral arrangements (Flores *et al*., 2017). Another species, *Heliconia psittacorum,* is often cultivated for its ornamental appeal, featuring smaller, more delicate flowers that bear resemblance to a parrot's beak (Malakar and Biswas, 2022). Furthermore, *Heliconia wagneriana* is acknowledged for its robust bracts, which confer resilience to more adverse environmental conditions, thus rendering it a favored option in both landscaping and floriculture (Ortiz-Curiel *et al*., 2023).

Flores *et al.* (2017) noted the recognition of a distinct *Heliconia* species with hanging blooms, discovered in Panama's Chucantí Private Nature Reserve, which underscores the active

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research into Heliconia biodiversity. This newly recognized species exemplifies the ecological variety inherent within the genus, contributing to a multitude of microhabitats in tropical forest ecosystems (Rojas *et al*., 2024).

2.6 Cultivation of *Heliconia* species

2.6.1 Climatic Requirements

Heliconia species thrive under specific climatic conditions that significantly influence their growth and flower production. Key climatic requirements include optimal temperature, light exposure, and humidity levels. Cultivating Heliconia species requires specific climatic conditions, primarily warm temperatures, and high humidity, typical of their native tropical environments (Santhosh *et al.*, 2018). According to Cabral and Benedetto (2010), Heliconia species require relatively high temperatures ideally around 32 °C during the day and 20 °C at night, and moderate irradiance (250-710 µmol·m-2·s-1) for optimal growth and productivity. Gilman and Meerow (2007) reported similar findings.

The influence of photoperiod is also notable; certain cultivars like *H. rauliniana* respond positively to shorter photoperiods, while others like cv. Fire Bird thrive under longer photoperiods (Gomes *et al*., 2016). Furthermore, greenhouses and shade structures are essential in regions with extreme temperatures to ensure survival and productivity (Cabral and Benedetto, 2010).

2.6.2 Soil Requirement

Linares *et al.* (2018) reported that *Heliconia* species require well-drained, fertile soil enriched with organic matter, as organic amendments enhance soil properties and support optimal growth conditions for these plants. Furthermore, Gilman and Meerow (2007) also noted that

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these plants require well-drained soils. The authors however found that they can tolerate moderate drought.

Heliconia species also thrive in organic-rich soils, and although they can tolerate a range of soil types, soil pH levels between 5.5 and 6.5 are ideal for optimum growth (Trejo-Téllez, 2018). Substrates with high levels of organic matter are recommended for heliconia cultivation to enhance water retention and nutrient availability, improving growth and flowering outcomes (Linares *et al.,* 2016). *Heliconia* species thrive in substrates with good porosity, organic matter, and pH levels around neutral to slightly alkaline, as indicated by the study's findings on various substrate mixtures (Dos Santos *et al*, 2016).

2.6.3 Propagation

Propagation of Heliconia typically occurs through rhizome division, although some species can be propagated via seeds. According to Hernández-Meneses *et al.* (2018), *Heliconia* species propagation can be achieved through various methods, including micropropagation, seed germination, and rhizome division. Trejo-Téllez (2018) emphasized the importance of maintaining rhizome health to ensure successful propagation and disease resistance. Micropropagation techniques, particularly organogenesis, have been developed for species like *Heliconia collinsiana* and *H. nickeriensis,* utilizing specific concentrations of bencilaminopurina to induce shoot multiplication and rooting (Hernández-Meneses *et al*., 2018).

In vitro propagation protocols for hybrids such as *H. bihai* x *H. caribaea* have shown high survival rates during acclimatization, emphasizing the importance of pathogen-free seedlings (Colombo *et al*., 2016). Rodríguez *et al*. (2013) found that rhizomes serve as effective explants for establishing new plants, with successful disinfection methods enhancing survival rates. Pereira *et al*. (2016) noted that, despite the advancements in propagation methods, challenges

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such as microbial contamination and genetic diversity in breeding programmes remain critical for improving heliconia species for market demands.

2.6.4 Agronomic Practices

2.6.4.1 Fertilization

Fertilization plays a critical role in enhancing plant growth and productivity, particularly for commercially valuable plants such as Heliconia. The application of fertilizers rich in nitrogen and potassium is recommended to enhance the vibrant colours of the bracts and increase plant vigor (Ortiz Curiel *et al*., 2023). According to Linares-Gabriel *et al.* (2016) the combined use of organic and inorganic fertilizers significantly improved the plant height, leaf area, and root development of *Heliconia psittacorum*. Similarly, Cabral and Di Benedetto (2010) observed that organic amendments positively impacted the production of heliconia flowers, enhancing both the quality and yield of cut flowers.

2.6.4.2 Pest Management

Effective pest management is essential for protecting *Heliconia* species from damage caused by insects. Several strategies for managing insect pests in ornamental horticulture exist. Some of these strategies include biological control and chemical applications. Dos Santos *et al*. (2016) reported that heliconia plants, when grown in appropriate substrates, exhibited greater resistance to common pests such as aphids and mites. The study underscored the importance of substrate selection in pest management. Colombo *et al*. (2016) also found that the use of organic matter in substrates not only promoted plant growth but also improved plant resilience against pests. According to Santhosh *et al*. (2018), pest management remains a crucial aspect of Heliconia cultivation, as the plants are prone to infestations by aphids, mealybugs, and spider mites, which can affect the aesthetic quality of the foliage and flowers.

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2.6.4.3 Irrigation

Another essential component of Heliconia cultivation is irrigation. Malakar and Biswas (2022) noted that, irrigation is essential in areas without sufficient rainfall, as most Heliconia species require moist conditions to grow effectively. According to Barcinas (2001) even though Heliconia do not do well in waterlogged areas, they require significant amount of water for proper growth and development.

Irrigation management is critical for optimizing water use efficiency and ensuring the proper growth of ornamental plants like Heliconia. Irrigation frequency and the type of water delivery system can significantly affect plant growth, flower yield, and soil moisture retention. According to Hernandez-Meneses *et al*. (2018), the use of drip irrigation combined with organic amendments led to improved water retention in the soil, promoting healthy root growth in *Heliconia* species. Proper irrigation, especially in regions with variable rainfall, ensures that plants maintain adequate hydration without water stress. Additionally, the study by Pereira *et al.* (2016) showed that well-regulated irrigation could enhance the genetic diversity and phenotypic expression in Heliconia families, improving their commercial value.

2.7 Growth media

2.7.1 Effect of growth media on the agronomic traits of *Heliconia psittacorum*

The choice of growth medium is a critical factor affecting the agronomic performance of *Heliconia psittacorum*. Evans *et al.* (1996) noted that, substrates such as peat, coconut coir, perlite, and composted bark have been commonly used in the cultivation of Heliconia species, each offering unique properties that influence water retention, aeration, and nutrient availability. Awang *et al.* (2009) found that coconut coir, for example, provides excellent water-holding capacity and aeration, which can enhance root development and overall plant vigour in Heliconia.

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On the contrary, peat-based substrates, even though rich in organic matter, can sometimes lead to waterlogging and reduced aeration, negatively impacting root health and growth. The incorporation of inorganic components like perlite, according to Handreck and Black (2002), can improve drainage and reduce compaction, creating a more favourable environment for root growth and nutrient uptake, ultimately enhancing the quality and yield of cut flowers.

2.7.2 Effect of growth media on the sprouting time of *Heliconia psittacorum*

Hernández-Moreno et al. (2020) reported that organic amendments such as chicken manure improve soil fertility by enhancing nutrient availability and microbial activity, thus accelerating plant physiological processes, including germination and sprouting. Similarly, Akande et al. (2013) found that organic materials like decomposed oil palm stems also contribute to better water retention and aeration, which are vital for root development and faster sprouting.

On the contrary, Malakar et al. (2019) noted that substrates with higher sand content may not provide sufficient nutrients or water retention to support rapid sprouting. According to Chong (2005), however, organic-enriched loamy soils have the capacity to promote sprouting across varying conditions. There is no doubt that organic manure plays a crucial role in reducing the sprouting time of *Heliconia psittacorum*.

2.7.3 Effect of growth media on the number of sprouts of *Heliconia psittacorum*

The positive impact of organic manure such as chicken manure in enhancing the sprout production of *Heliconia psittacorum* has been reported by a number of studies. According to Hernández-Moreno et al. (2020), chicken manure is known for its rich nutrient content, particularly nitrogen, which enhances vegetative growth and sprouting. Malakar et al. (2019) also reported that, despite the ability of river sand and coconut fibre to provide good aeration and drainage, these substrates lack the essential nutrients required for robust sprout

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development in heliconia plants. Akande et al. (2013) also observed that organic-rich substrates consistently promote higher sprout numbers, likely due to their improved nutrient retention and enhanced microbial activity. It is therefore fair to conclude that substrates rich in organic matter provide a more conducive environment for sprout production in *Heliconia psittacorum* over time.

2.7.4 Effect of growth media on the time to flowering of *Heliconia psittacorum*

Decomposed organic matter, rich in essential nutrients, can effectively accelerate the reproductive phase of *Heliconia* by promoting early flowering. Hernández-Moreno et al. (2020) reported that organic substrates improve soil structure, nutrient availability, and water retention, creating optimal conditions for flowering. Akande et al. (2013) noted that despite the fact that clayey soils are typically nutrient-dense, their heavy texture may delay flowering compared to organic-rich, loamy substrates.

Sand-dominant substrates, while promoting good drainage, may fail to retain sufficient nutrients and moisture, which are critical for inducing flowering (Malakar et al., 2019). For this reason, Chong (2005) emphasized the importance of nutrient-rich substrates for flowering, as nutrient deficiency can delay or prevent reproductive development.

2.7.5 Effect of growth media on the stem height development of *Heliconia psittacorum*

The growth media composition (substrate) is critical in regulating the stem height development in *Heliconia psittacorum*. Malakar et al. (2019) stated that substrates with high organic content and moisture retention properties can promote rapid initial development by enhancing nutrient availability and water retention. As a result, plants grown in nutrient-rich media may have an early-stage growth advantage over their counterparts. However, as plant growth advances in age, its nutrient demand rises, as noted by Taniguchi et al. (2018).

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Atzori et al. (2021) reported that coconut fibre alone as a growth medium may not provide a balanced supply of moisture and nutrients to support optimal growth in tropical ornamental species. As a result, using coconut fibre alone could lead to poor plant development and consequently negatively affect stem height growth. Silva et al. (2018) found that poor drainage and low aeration associated with compact soils can impede root growth and nutrient uptake. It is worth noting that substrates enriched with organic matter, particularly chicken manure and decomposed organic materials, significantly boost stem elongation in *Heliconia*. This phenomenon could be attributed to enhanced nutrient availability and improved soil structure (Silva et al., 2019; Chand et al., 2021).

2.7.6 Effect of growth media on the stem girth development of *Heliconia psittacorum*

As noted earlier, substrate composition influences stem girth development in *Heliconia psittacorum*. According to Silva et al. (2018), the compact structure of poorly aerated soils often limits root expansion, aeration, and water drainage, which can lead to restricted nutrient uptake and reduced stem development. On the contrary, other substrates, depending on their composition, provide more favourable conditions for stem girth expansion. According to Taniguchi et al. (2018), growth media consisting of chicken manure can support sustained plant growth as nutrient demands increase, likely due to the steady release of nutrients from the manure. Malakar et al. (2019) found that substrates rich in organic matter and possessing favourable water-holding capacity support early stem development. Atzori et al. (2021) noted that coconut fibre's high lignin content and water-holding properties could be advantageous for mid-stage plant growth.

2.7.7 Effect of growth media on the leaf development of *Heliconia psittacorum*

Substrates such as decomposed organic materials provide a high content of organic matter, which could enhance early leaf production through improved nutrient and water retention

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(Malakar et al., 2019). According to Atzori et al. (2021), there is enhanced root proliferation and nutrient uptake as plants adapt to coarser substrates with favourable physical characteristics. Silva et al. (2018) indicated that plants grown in substrates containing chicken manure and loamy soil may produce a significant number of leaves due to the nutrient-rich and balanced environment provided by these media. Silva et al. (2018) further suggested that compact soils may initially restrict growth due to poor aeration and drainage but may gradually release bound nutrients later in the growth cycle, supporting delayed yet sustained leaf production.

2.7.8 Effect of growth media on the leaf area development of *Heliconia psittacorum*

Findings have shown that the leaf area development of *Heliconia psittacorum* is affected by the growth media. Taniguchi et al. (2018) reported that growth substrates such as loamy soil amended with organic materials are effective in supporting robust leaf expansion, likely due to improved nutrient availability and balanced moisture retention, which collectively enhance photosynthetic capacity and promote cell expansion in leaf tissues. Similar findings were made by Malakar et al. (2019), who reported that organic-rich growth media provide balanced nutrition that favours vegetative growth. Growth media such as clayey soils may not support leaf expansion, and this could be linked to the limited aeration and drainage typical of such substrates, which impede root respiration and nutrient uptake, thereby restricting leaf growth (Silva et al., 2018). On the other hand, Atzori et al. (2021) noted that organic-rich substrates provide an advantage during the peak growth phases of plants.

2.7.9 Effect of growth media on the chlorophyll content of *Heliconia psittacorum*

Chlorophyll content is a vital indicator of plant health, influencing photosynthetic efficiency and overall plant productivity. Zhao *et al*. (2021) reported that nitrogen is one of the nutrients that is crucial for chlorophyll synthesis in a plant. As a result, a reduction in nitrogen content

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will translate into a reduction in the chlorophyll content of the plant. Singh *et al*. (2018) also observed that a delay in the release of nutrients to the plant will subsequently affect chlorophyll production. Alam *et al*. (2019) noted that nutrient-rich substrates like those containing organic matter, such as chicken manure, tend to support higher initial chlorophyll synthesis but may see rapid depletion without proper replenishment.

2.7.10 Effect of growth media on the root and shoot Biomass of *Heliconia psittacorum*

Growth media composition plays a crucial role in plant development and biomass allocation. According to Srivastava *et al*. (2019), growth media such as clayey soil may provide better structural support and nutrient availability conducive to shoot growth. The resultant effect of this is an increase in the shoot biomass of the plant. Kumar *et al*. (2021) state that clayey soils have high moisture retention capabilities and nutrient profiles and can influence the shoot and root biomass development in plants. Similarly, Liu *et al*. (2018) reported that the higher biomass in shoots and roots in clayey soils could be attributed to its physical and chemical properties, which may enhance water and nutrient retention, supporting better growth compared to other substrates like decomposed stems or sand mixes.

2.8 Harvesting of flowers of Heliconia species

2.8.1 Time and Stage of Harvest of Heliconia Flowers

The timing and developmental stage at which *Heliconia* flowers are harvested play critical roles in ensuring optimal quality, longevity, and aesthetic value. Jezdinská Slezák *et al*. (2022) indicated that flowers harvested at an earlier stage of development have an extended vase life compared to those harvested at full maturity, as premature blooms are less susceptible to rapid water loss and microbial growth. Optimal harvest time also varies with environmental factors; harvesting during cooler periods, such as early morning or late evening, minimizes water loss

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and enhances flower quality by preserving turgor pressure and delaying wilting (Nowak and Rudnicki, 1990).

Heliconia species benefit from being harvested when bracts are partially open, as this stage promotes both visual appeal and durability during storage and transport (Liju, 2013). As posited by Reid and Jiang (2012), the threshold of harvest maturity for a cut-flower crop is defined as the developmental phase wherein harvested buds can fully open and exhibit an adequate display longevity post-distribution. Numerous floral species are optimally harvested in the bud stage and subsequently allowed to open following storage, transportation, or distribution periods.

2.8.2 Harvest Containers

Appropriate containers used during harvesting can significantly influence the quality of *Heliconia* flowers by minimizing mechanical damage and reducing contamination. Containers should ideally be designed to support the upright positioning of cut stems, preventing bruising and breakage during handling (Malakar *et al*., 2023). The authors further indicated that, for tropical flowers like *Heliconia*, which are sensitive to water loss, containers that facilitate hydration during transport are recommended. Adding hydration solutions can also maintain turgidity and support nutrient intake, helping flowers retain quality throughout the supply chain. Deshwal *et al*. (2020) posited that in the selection of containers for the preservation of harvested floral specimens, it is advisable to prioritize plastic containers rather than their metallic counterparts, due to the potential for corrosion in metal containers which may obstruct the conductive tissues of the stems.

2.8.3 Packaging and Transportation of Cut Flowers

Proper packaging and transport are essential in extending the postharvest life of *Heliconia* flowers. Cut flowers are often packed in boxes made of cardboard during transportation. Packaging should prevent dehydration, maintain structural integrity, and provide ventilation to

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prevent ethylene accumulation, which accelerates senescence (Reid and Jiang, 2012). Temperature-controlled environments during transportation are especially crucial for tropical flowers, as exposure to high temperatures can exacerbate water loss and reduce vase life. Packaging innovations, such as pre-treated water-absorbing pads and modified atmosphere packaging (MAP), are effective for reducing microbial contamination and maintaining humidity, both of which are important for *Heliconia*'s durability during long-distance transport (Salunkhe *et al*., 1990; Wilson *et al*., 2017).

2.9 Physiological Characteristics of Flowers

Flowers consist of specialized organs, namely sepals, petals, stamens, and carpels, which have evolved from leaf-like structures to fulfill reproductive functions (Maio and Moubayidin, 2024). The authors indicated that the symmetry and morphology of these organs contribute to diverse reproductive strategies, facilitating pollination and gamete protection. Borghi and Fernie (2021) indicated that flowers are rich in primary and secondary metabolites, which are crucial for attracting pollinators through scent and color. These metabolites according to Borghi and Fernie (2021) play protective roles against UV radiation and are involved in nectar production, essential for pollinator attraction.

Flowers have higher minimum epidermal conductance and water content compared to leaves, indicating a reliance on water for structural integrity (Roddy *et al*., 2023). According to Roddy (2024), the hydraulic efficiency of flowers varies significantly among species, influencing their water balance and overall reproductive success.

2.10 Senescence of Cut Flowers

Environmental factors such as temperature, light, and water significantly influence the senescence of cut flowers, affecting their longevity and quality. Elevated temperatures can accelerate metabolic processes, leading to increased respiration rates and quicker senescence

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in cut flowers. Xu *et al*. (2023) reported that proper temperature control during storage and transport is essential to minimize ethylene production, which is a key factor in flower aging.

Light quality and intensity also play a critical role in photosynthesis and carbohydrate accumulation, which are vital for flower health. According to Rezai *et al*. (2023), LED lighting can enhance flower water content and antioxidant activity, delaying senescence compared to other light sources. Furthermore, adequate water supply is crucial; insufficient hydration leads to vascular blockages and reduced vase life. Research has shown that rose cultivars with larger xylem diameters exhibit longer vase life due to better water absorption (Verdonk *et al*., 2023; Daneshmand *et al*., 2024).

2.11 Post-Harvest Handling of Cut Flowers

2.11.1 Water and Water Quality

The quality of water significantly impacts the post-harvest physiology of cut flowers, influencing their longevity, water uptake, and overall aesthetic appeal. Various studies highlight how different water types and their properties can either enhance or hinder the vase life of cut flowers. Water quality directly affects the vascular system of cut flowers, influencing their ability to absorb water. Poor water quality can lead to vascular blockages and increased sensitivity to environmental stressors, resulting in reduced flower longevity. For instance, rose cultivars with larger xylem diameters exhibited longer vase life due to enhanced water absorption (Daneshmand *et al*., 2024).

According to Hegazy and Ibrahim (2019), different water types, such as zamzam water and magnetic water, have been shown to improve water uptake and extend the vase life of cut flowers like roses. Asif *et al.* (2016) also reported that acidic water (pH 3.0-5.5) can inhibit microbial growth, promoting better water absorption and longevity in flowers.

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According to Asif *et al.* (2016), high bacterial counts in tap water can negatively affect the water balance and longevity of cut flowers, leading to premature wilting. The presence of certain ions in water can delay senescence, while high soluble salt content can interfere with water uptake and damage flower tissues (Asif *et al*., 2016; Sidhdharth and Nivethaa, 2020). Hutchinson (2013) also reported that the addition of chemical preservatives to vase solutions can enhance the effects of water quality, significantly increasing the vase life and floret opening of flowers like Lisianthus.

2.11.2 Pulsing treatment

The pulsing treatment of heliconia cut flowers significantly enhances their water uptake and absorption rates, which is crucial for extending their vase life. Various studies indicate that treatments such as gibberellic acid (GA3) and wax coatings can improve these parameters, leading to better overall flower quality.

In a study by Souza *et al*. (2015) on *Heliconia psittacorum*, pulsing with GA3 increased water uptake by 47% within the first four days, although it decreased towards the end of the storage period. Furthermore, the authors reported that the treatment resulted in improved flower opening and maintained quality, with a vase life of approximately ten days at room temperature.

Carrera-Alvarado *et al*. (2021) also found that Wax coatings on *Heliconia wagneriana* reduced fresh weight loss and improved water absorption, extending vase life by up to two additional days. This method according to the authors is particularly effective in maintaining turgidity and reducing oxidative stress, which is essential for water retention.

Research findings have shown that pulsing treatments with sucrose and other chemicals have been shown to enhance water uptake in various cut flowers, indicating a broader applicability of these methods in horticulture (Sharma and Thakur, 2020; Amiri et al., 2009). According to

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Manzoor et al. (2024), addressing physiological issues like xylem blockage through chemical treatments can further improve water relations and prolong vase life. It is important to note that, while pulsing treatments generally enhance water uptake, it is essential to consider the specific conditions and treatments applied, as not all methods yield the same results across different flower species.

2.11 Vase Life of Cut Flowers

Vase life is the period during which a cut flower or foliage retains its appearance in a vase. This is a major consideration in plant species suitable for use in the floral industry. Plants with a long vase life are far more desirable than those with a short vase life. Aalifar *et al*. (2020). Post-harvest treatments significantly enhance the vase life of cut heliconia flowers by addressing physiological challenges such as water uptake and microbial growth. Various methods, including chemical preservatives, wax coatings, and sucrose solutions, have been shown to improve the longevity and overall quality of cut flowers.

The use of chemical preservatives, such as Silver thiosulphate and Aloe vera gel, effectively reduces microbial populations and enhances vase life. Aloe vera gel at 4% resulted in a vase life of 12 days, significantly outperforming controls (Shokalu *et al*., 2021). According to Manzoor *et al.* (2024), chemical treatments also minimize vascular blockage caused by phenolic compounds, improving water uptake and flower freshness.

Waxing heliconia stems has been shown to maintain fresh weight and extend vase life by up to 2 days compared to controls. This treatment reduces oxidative stress and enhances turgidity (Carrera-Alvarado *et al.*, 2021). Furthermore, Sucrose solutions, particularly at concentrations of 10%, have been effective in prolonging vase life by improving water balance and delaying senescence. A combination of sucrose and Hydraflor® 100 yielded a vase life of 22.8 days (Carrera-Alvarado and Baltazar-Bernal, 2022). Costa *et al*. (2021) noted that while these

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treatments are beneficial, it is essential to consider the potential for chilling injury in heliconia, which can occur if stored at inappropriate temperatures.

2.12 Effect of Vase Solutions on the Visual Appearance of Cut Flowers

The visual appearance of cut flowers is significantly influenced by the composition of vase solutions, which can enhance their longevity and aesthetic qualities. Key components include sugars, acids, and antimicrobial agents, each playing a crucial role in maintaining flower health and appearance.

Sugars like sucrose and glucose serve as energy sources for cut flowers, promoting better hydration and flower opening (Sudaria *et al*., 2017; Özdal, 2024). According to Sudaria *et al*. (2017), solutions with 2% sucrose combined with hydroxyquinoline sulfate (HQS) showed improved flower head diameter and vase life in roses. Furthermore, rosemary and thyme extracts combined with sucrose have shown promise in maintaining flower quality and extending vase life (Sarhan *et al*., 2023).

Alkaç *et al*. (2023) reported that the use of citric acid (200 mg/L) effectively reduced bacterial populations and improved water uptake in carnations, leading to enhanced vase life. Similar results were observed in tulips, where citric acid also contributed to longer display life (Ullah *et al*., 2022). The pH of a vase solution has a significant impact on the vase life of cut flowers. Othman *et al*. (2023) noted that maintaining a pH of 3.5 - 4.0 in vase solutions consistently improved the vase life of various flowers, including roses and lilies, compared to neutral or basic solutions.

Antimicrobial agents such as nanoparticles and bactericides have also been shown to influence the vase life of cut flowers. According to Özdal (2024), solutions infused with nano copper and silver significantly extended the vase life of narcissus flowers by reducing microbial growth.

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Similarly, silver nitrate was effective in prolonging vase life by acting as a bactericide, especially when combined with sugars (Othman *et al*., 2023). Again, Sarhan *et al*. (2023) found that solutions containing $AgNO_3$ and sucrose have been effective in extending the vase life of carnations, with optimal results achieved when combined with other agents like boric acid and 8-hydroxyquinoline sulfate.

While these components generally enhance the visual appeal and longevity of cut flowers, excessive sugar use or inappropriate pH levels can lead to adverse effects, such as increased bacterial growth or reduced water uptake. Thus, a balanced approach in formulating vase solutions is crucial for optimal results.

2.13 Effect of Vase Solutions on the Deterioration of Cut Flowers

Vase solutions significantly affect the deterioration of cut flowers, as various treatments can enhance vase life and overall quality. Research indicates that specific chemical and organic compounds in vase solutions can mitigate microbial contamination, improve water uptake, and maintain physiological integrity, ultimately prolonging the lifespan of cut flowers (Doğan *et al*., 2024; Alkaç *et al*., 2023; Chen *et al*., 2024).

Solutions with 200-250 mg/L citric acid have been shown to significantly enhance the vase life of flowers like Gerbera and carnation by reducing bacterial populations and promoting water uptake (Doğan *et al*., 2024; Alkaç *et al*., 2023). Similarly, a combination of sucrose, melatonin, and citric acid in peonies extended the vase life from 4.7 to 8.9 days, indicating the effectiveness of tailored solutions (Chen *et al*., 2024). A study by Jianjun *et al*. (2021) found that a domestic vase solution containing 20 g/L sugar and 28 ml/L lemon juice significantly extended the vase life of Gladiolus flowers. A combination of 2% sucrose with 15 ppm citric acid yielded the longest vase life for roses (Aryal *et al*., 2019). For lilies, a 20% sucrose solution combined with 50 ppm silver nitrate ($AgNO_3$) was optimal (Brahma *et al*., 2023).

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Thymol and salicylic acid play a major role in reducing the rate of deterioration in cut flowers. While thymol at high concentrations negatively impacted flower quality, salicylic acid combined with sucrose improved vase life and reduced microbial growth (Doğan *et a*l., 2024; Alkaç et al., 2023). According to Sarhan *et al*. (2023). Natural extracts like rosemary and thyme, according to Sarhan *et al.* (2023) when combined with sucrose, also contributed positively to vase life and slowed down the rate of deterioration.

2.14 Effect of different preservative solutions on the Temperature, Relative Humidity, and CO_2 concentration in the Storage chamber of cut flowers

The impact of preservative solutions on temperature, CO_2 levels, and relative humidity in cut flower storage chambers is significant for maintaining flower quality and longevity. Various studies highlight how these factors interact to optimize the storage environment for cut flowers, ensuring they remain fresh for extended periods.

Low temperatures (around 2°C to 6°C) are crucial for slowing down respiration rates and delaying senescence in cut flowers (Badawy *et al*., 2007; Gendy & Hamad, 2011). High humidity (80-95%) in conjunction with low temperatures helps maintain turgidity and reduces water loss, essential for flower longevity (Chen *et al*., 2024; Pal *et al*., 2003).

The use of preservative solutions can influence CO_2 production by affecting respiration rates. For instance, solutions that provide carbohydrates can enhance respiration, but controlled environments can mitigate excessive CO_2 buildup (Sao & Verma, 2020; Pal *et al*., 2003). Maintaining optimal CO_2 levels is vital to prevent ethylene production, which accelerates flower senescence (Sao & Verma, 2020).

High relative humidity levels (80-95%) are beneficial as they reduce water loss and maintain flower quality, as evidenced by improved vase life and reduced wilting (Chen *et al*., 2024; Pal *et al*., 2003). Preservative solutions that include sucrose and other compounds can further

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enhance the effects of high humidity by improving water uptake and reducing microbial growth (Badawy *et al*., 2007).

2.15 Summary

The assessment of different substrates for cultivating *Heliconia psittacorum* cut flowers underscores how crucial nutrient-rich, organic soils are for encouraging quicker growth, more blooms, and healthier plants compared to sandy or clay options. These ideal growing mediums not only enhance flower quality and longevity but also work wonders when paired with effective harvesting methods such as picking during cooler periods when the bracts are just starting to open and careful handling practices, including proper hydration, packaging, and temperature management during transport. Additionally, postharvest treatments such as using clean, slightly acidic water with additives, pulsing with gibberellic acid or wax coatings, and applying balanced vase solutions that include sugars and antimicrobial agents can significantly improve water absorption, minimize microbial decay, and prolong vase life. By combining these substrate choices and postharvest strategies, we can ensure that *Heliconia psittacorum* cut flowers stay vibrant and resilient from the moment they are grown to when they are displayed in a vase.

INTEGRI PROCEDAMUS

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CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental location

The cultivation of the crop was carried out in the Sinna's Garden of the Department of Crop Science, Faculty of Agriculture, University of Ghana, Legon, from 12th March, 2023, to 23rd February, 2024, and repeated from 29th May, 2023, to 10th May, 2024. The vase life study, on the other hand, was carried out in the Department of Crop Science from 6th to 20th November, 2023, and repeated from 29th July, 2024 to 12th August, 2024. Geographically, the campus lies within latitudes 5° 38' 59.99" N and longitude 0° 10' 60.00" E (CERSGIS-UG, 2023) within the Ayawaso West Municipal in the Greater Accra Region of Ghana.

3.2 Climatic conditions

The area falls within the Coastal Savannah zone (FAO-UN, 2006) with two main distinct patterns of rainfall. The major season starts from April to July, whereas the minor season commences from August until October (MOFA, 2023).

The area experiences a mean temperature of 27.5 °C, an average number of rainy days of 136, 190 hours of sunshine, relative humidity of 83%, and average annual rainfall of 715 mm (Weather-and-climate.com, 2023).

3.3 Treatments

Two sets of treatments were involved. The first set consists of six potting media that were used for the cultivation of the crop, whereas the second set comprises four preservative solutions that were used for the vase life studies (Table 3.1 and 3.2).

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Table 3.1: Potting media used for the cultivation of *Heliconia psittacorum*

Treatment	Growth media
T_1	Decomposed Oil Palm stems (DOS);
T_2	Top soil + Chicken manure (TS + CM) (1:1)
T_3	Top soil + Coconut Fibre (TS + CF) (1:1)
T_4	River sand + Coconut Fibre (RS + CF) (1:1)
T_5	River sand + Chicken manure (RS + CM) (1:1)
T_6	Clayey soil (CS) (control)

Table 3.2: : Substrates used for the vase life studies of *Heliconia psittacorum* cut flowers

Treatment	Substrate
T_1	0% sucrose solution (Distilled water only)
T_2	10 % sucrose solution (w/v)
T_3	15 % sucrose solution (w/v),
T_4	20 % sucrose solution (w/v)

3.4 Sources of Materials

The Heliconia rhizomes were obtained from the Department of Horticulture, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology in Kumasi. This plant was selected based on value and usage.

The black polythene bags (36 cm × 29 cm × 91cm) used for the experiment were purchased from the AGRIMAT shop, at Madina, a suburb of Accra. The sucrose, distilled water, cotton wool, and the 100 mL measuring glass cylinders measuring 3cm x 6cm x 24cm were all purchased from the Zinabel Laboratory Equipment Enterprise shop near Odo rice at Kwame Nkrumah Circle, Accra. The yellow coverslips were locally produced by the researcher, whereas the nano tapes were purchased from a private vendor at Labadi, Accra.

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The black clayey soil was also collected with a soil auger at a depth of about 0-15 cm from the land close to MDK, Ghana Flowers and Greens Limited, Dawhenya. The river sand was obtained from a construction site at American House, East Legon, whereas the coconut fibre was purchased from a private vendor at Trinity junction, East Legon. The top soil was obtained in front of the Botanical Garden at Legon main campus, and the decomposed oil palm stems from an oil palm plantation at Agape, a suburb of Accra in the Ga Central municipality. Finally, the chicken manure was obtained from a poultry farm at Anyaa in the Ga Central municipality.

3.4.1. Analysis of Potting Media

Before planting, some physico-chemical characteristics such as pH, EC, %N, %P, %K, %C, and %Mg of the potting media were examined singly and also in combined quantities at the Soil Science Laboratory, Department of Soil Science, University of Ghana, Legon, using the standard Laboratory test as described by (Mylavarapu, 2009).

Media samples were taken to the laboratory, air-dried in the shade and grounded with a wooden roller thereafter sieved through a 2 mm stainless steel sieve and stored in polythene bags which was used for the chemical assay.

3.4.1.1 Determination of pH

About 20 g of each media sample was mixed with 40 ml of distilled water in a 100 ml beaker and stirred thoroughly to form a suspension. The pH was determined by immersing the electrodes of the pH meter into the suspension, and the pH values displayed on the screen were recorded.

3.4.1.2 Determination of Total bases (K and Mg).

One gram of each sample was weighed and transferred into test tubes, and 10 ml of tannery mixture (perchloric acid + nitric acid) was added to each. The samples were heated for about 5 hours until the solution was clear. After heating, the samples were diluted and filtered through

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Whatman No. 42 filter paper into 250 ml volumetric flasks, except for river sand, which was transferred into a 200 ml volumetric flask and topped up to the mark. The concentrations of K and Mg were determined with the Atomic Absorption Spectrophotometer.

3.4.1.3 Determination of Total Phosphorus(P)

For Total P, 1 ml of the extract was pipetted and transferred into a 50 ml volumetric flask. A drop of nitrophenol was added, and then a drop of ammonia was also added. 8 ml of ascorbic acid was further added and then left to stand until a blue colour was observed. Distilled water was added to the mark, and then the phosphorus content was determined using the ultraviolet spectrophotometer.

3.4.1.4 Determination of Carbon Content

Before total C and N analysis, the presence of inorganic carbon was tested qualitatively on a separate sample by adding a few drops of acid (1N HCl) to a small quantity of the pulverized media in a small weigh beaker. The evolution of fine bubbles indicated the presence of inorganic carbon. Media detected to contain inorganic carbon were pre-treated with acid fumigation.

For carbon content, 0.05 g of the samples was weighed and transferred into conical flasks. 10 mls of potassium dichromate was added and the 20 mls of sulphuric acid were added. It was heated and then left for about an hour. 200 mls of distilled water was added and then 10 mls of auto phosphoric acid was added. 1 ml of indicator was added and then titrated with ferrous ammonium sulphate.

3.4.1.5 Determination of Nitrogen content

For nitrogen content, 0.1 g of the samples was weighed and transferred to test tubes. 10 ml of sulphuric acid was added and heated until the solution was clear. The samples were then diluted

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and transferred into 50 ml volumetric flasks and topped up to the mark with distilled water. The samples were distilled with sodium hydroxide and then titrated with 0.01 M hydrochloric acid.

Table 3.3: Some physico-chemical analysis of potting media used

Substrate	pH	EC	%N	%P	%K	%C	%Mg	C/N Ratio
DOS	8.1	0.058	1.12	0.12	0.98	21.29	0.30	19.01
TS + CM	7.5	0.020	0.98	0.28	0.418	38.20	0.213	38.98
TS + CF	7.3	1.539	0.42	0.10	0.503	13.99	0.142	33.31
RS + CF	7.4	0.57	0.22	0.04	0.133	5.46	0.062	24.82
RS + CM	7.9	1.527	0.37	0.33	0.199	15.07	0.198	40.73
CS	8.3	0.59	0.21	0.07	0.156	24.7	0.605	117.62
TS	7.5	0.766	0.42	0.11	0.360	15.59	0.131	37.12
CM	7.5	0.055	1.4	0.83	0.596	46.43	0.692	33.16
CF	6.9	0.025	1.26	0.16	1.216	40.22	0.270	31.92
RS	7.6	0.035	0.01	0.02	0.026	0.11	0.051	11.00

DOS = Decomposed Oil Palm stems, **TS** + **CM** = Top soil + Chicken manure, **TS** + **CF** = Top soil + Coconut fibre, **RS** + **CF** = River sand + Coconut fibre, **RS** + **CM** = River sand + Chicken manure, **CS** = Clayey soil

3.5 Experimental design

3.5.1 Experimental design for cultivation

The experimental area is surrounded by immovable physical structures, which cast shadow on some of the plants at certain times of the day. The shadow stays for some time before disappearing. All the plants, for that matter, do not have equal amount of sunlight at a particular time. Based on this, a Randomized Complete Block Design (RCBD) was adopted for this study. Six treatments were employed in this design. Each treatment was made up of three pots, which were replicated four times, giving a total of seventy-two pots.

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Plate 1: A complete shadow cast on plants in Block 4 at 14:15 hours GMT:

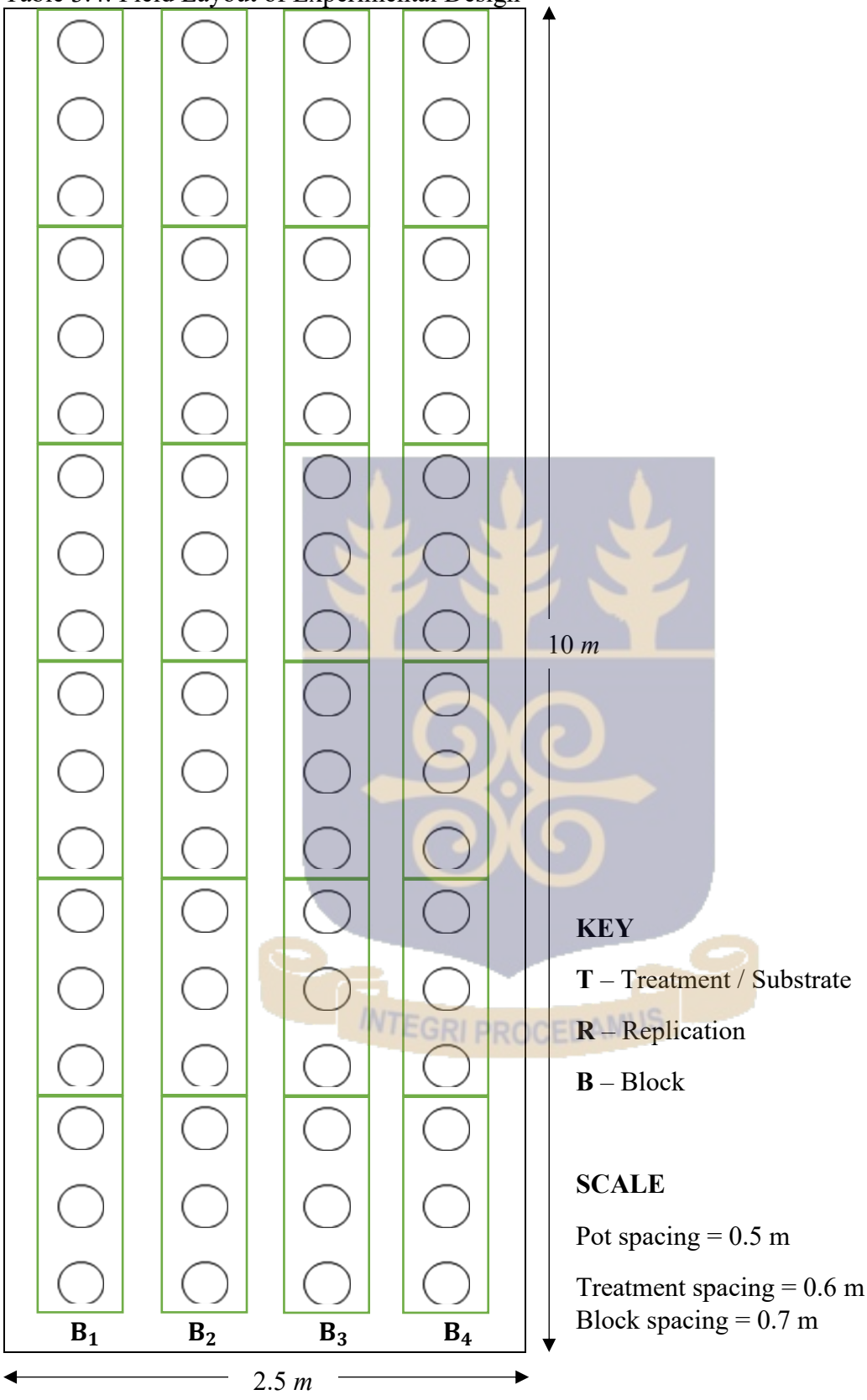
3.5.2 Experimental Design for Vase Life Studies

The vase life study, on the other hand, was set up in a Completely Randomized Design (CRD) with four treatments replicated three times. Each treatment consists of three flower vases (100 ml measuring cylinder), giving a total of thirty-six vases. The treatments were assigned completely at random to each experimental unit in a controlled or homogeneous environment.


Plate 2: Cut flowers undergoing vase life studies

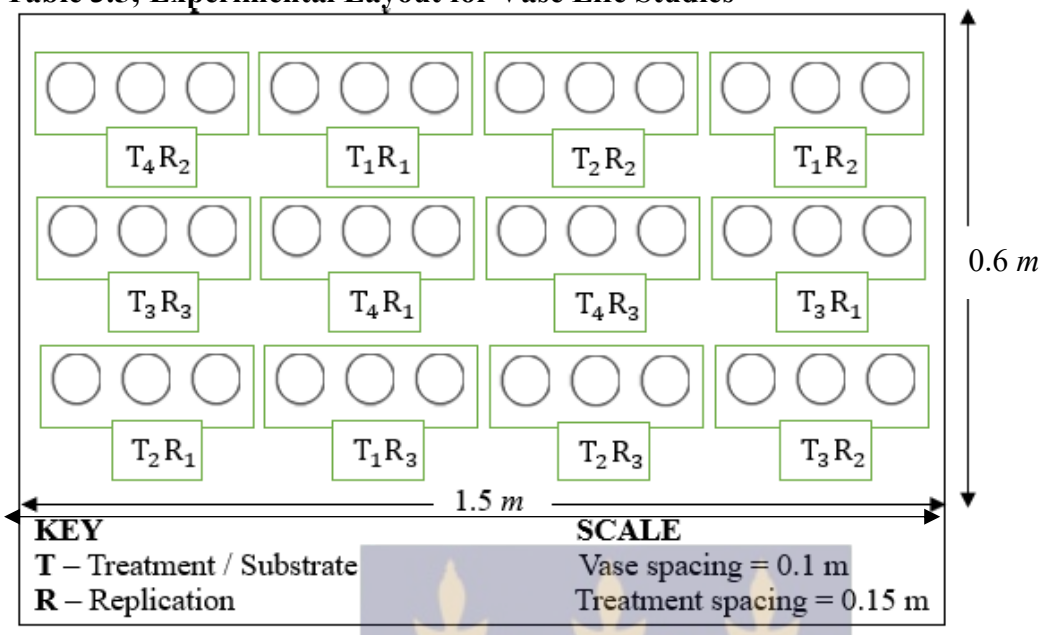
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Table 3.4: Field Layout of Experimental Design



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Table 3.5; Experimental Layout for Vase Life Studies



3.6 Procedure

3.6.1 Vase Solution Uptake (VSU) in (mls)

The initial volume of the vase solutions (i.e., 100 *mls*) was noted as $\boldsymbol{W_1}$ on day 0 and day 7 after renewal of the vase solutions, and the final volume on day 7 and day 14, also noted as $\boldsymbol{W_2}$. **VSU** by cut flowers on days 7 and 14 was calculated as = $\boldsymbol{W_1}$ - $\boldsymbol{W_2}$

3.6.2 Cultivation of the plant

The mixed media was measured in an equal ratio of 1:1, except the clayey soil and the decomposed oil palm stems, which were used singly. Prior to filling of the pots, the media was sun-dried for seventy-hours to kill all pathogens that may be present to avoid disease incidence. The experimental plots were cleared and mapped out. Clearing was done on the 1st of March, 2023. Planting of the *Heliconia psittacorum* rhizomes was done on the 12th of March, 2023, with a repeat of the setup on the 29th of May, 2023. Various cultural practices were carried out periodically throughout the study.

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3.6.3 Management practices

3.6.3.1 Weed control

Weeds in and around the pots were controlled periodically by hand pulling. This was done to prevent the weeds from competing with the crops for nutrients, water, and sunlight.

3.6.3.2 Watering

Watering was done on periodic basis throughout the growth period. About 250 mls of water was discharged at the base of each plant using a watering can.

3.6.3.3 Stirring

Stirring was carried out using a hand fork to loosen the soil and promote aeration, infiltration, and percolation of water.

3.6.3.4 Pruning

Dry and dead leaves were removed periodically using secateurs to promote air circulation.

3.6.3.5 Fertilizer application Stirring

Since Heliconia is a heavy feeder, 10g of NPK 15:1515 was applied to each plant periodically beginning from the ninth week.

3.6.3.6 Pest and Disease Control

Incidence of whiteflies and ants was observed beneath the leaves of plants. A mixture of K-Othrine SC and Sulfa 80 WDG in the ratio 1:2 was applied at a rate of one *litre* per m^2.



Plate 3: Incidence of whiteflies beneath the leaf.

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3.6.4 Vase Life Studies

Forty plant materials of *Heliconia psittacorum* were collected at about 05:00 hours Greenwich Mean Time (GMT.). To enhance longevity, the cut stems were hydrated by quickly placing them in a clean bucket containing distilled water (Haynes & Steil, 2023). The flowers were harvested at the stage of two to three buds opening. Thirty-six of the plant materials were carefully selected and all diseased parts removed to prevent the possibility of having diseases affecting the results of the study. Also, to avoid any form of crushing of the xylem cells which can lead to vascular blockage of water pathway into the stalk, flower stems were cut diagonally using a sharp knife under water. All the leaves were pruned to lessen transpiration.

The fresh weight of each cut flower stem was measured using an electronic scale before immersing it in the vase solution. The cut flower stems were passed through a rubber cover slip with holes and cotton wool fittings to ensure that cut flowers stood well in the vases to prevent evaporation and facilitate absorption during the vase life period. Adhesive nano tapes were used to keep the base of the flower vases in position to prevent them from toppling over.

Before the commencement of the vase life studies, each cut flower treatment was confined in an enclosed and airtight chamber for ten minutes, and the amount of CO_2 released at a prevailing temperature and relative humidity were recorded at two-minute intervals using an Air Quality Monitoring Instrument, I Q Air brand, model - Air Visual Pro. 48 hours were used for the preparation of the chamber before the commencement of the CO_2 reading. A petri dish containing a 2 Molar solution of sodium hydroxide was placed in the enclosed chamber for 24 hours to absorb all the CO_2 in the chamber (Wang *et al*., 2020) after which lime water was placed in the chamber for another 24 hours to ensure that there was no CO_2 present in the chamber. This was repeated on day 7 after recutting of flower stems and renewal of vase solutions.

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The vases containing the treatments and the individual cut-flowers were finally arranged in a Completely Randomized Design (CRD) and kept at room temperature for fourteen days. Evaluations were made, and the postharvest physiological characteristics of the flower stems were studied throughout the vase life period.

3.6.4.1 Recutting of flower stems

On the 7th day, stems of cut flowers were recut slightly to facilitate absorption. The stem ends were cut beneath water to prevent air embolism and vascular blockage (Van Doorn, 1997) after which they were hanged with cotton wool fittings to allow room for water infiltration.

3.6.4.2 Renewal of Vase Solutions

To prevent the growth of microorganisms, the formation of tyloses, the presence of air emboli in the vascular system, and the deposition of materials like gums and mucilage in the xylem artery lumen (Van Doorn, 1990) the solutions were replaced with clean, fresh ones on the 7th day.

3.7 Data collection

Two sets of data were collected. The first set was made up of data on some agronomic parameters of *Heliconia psittacorum,* whereas the second set was on vase life characteristics.

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3.7.1 Data on Agronomic parameters

Data on some agronomic parameters were taken every two weeks, from week nine to week 21, except for flowering, which was terminated at week 50. The number of sprouts per pot and plant biomass were recorded at week 50.

3.7.1.1 Weeks to sprouting (WTS)

Time taken for the rhizomes planted to begin showing signs of shoot formation was counted and recorded weekly.

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3.7.1.2 Stem Length (SL)

A measuring tape was used to measure plant stem height. The distance from the base of the plant to the apex of a new shoot was recorded as plant stem height.

3.7.1.3 Stem girth (SG)

A digital vernier caliper was used to measure stem girth five centimetres from the base of the plant.

3.7.1.4 Number of leaves (NOL)

The number of leaves produced by the plant was counted and recorded weekly.

3.7.1.5 Leaf Area (LA)

The longest and widest portions of the topmost leaf of the plant were multiplied by 0.74 to determine the leaf area (cm^2) as proposed by (Farias *et al*., 2013).

3.7.1.6 Chlorophyll content (CC)

The SPAD 502 chlorophyll meter was used to measure the chlorophyll content of a freshly fully opened leaf.

3.7.1.7 Number of sprouts per pot

The number of plants produced per pot was counted and recorded in week 50.

3.7.1.8 Plant biomass (g)

The fresh and dry weights of the above and below ground portions of the plant were measured in week 50 using a High Precision Digital Analytical Electronic Balance, RESHY Lab Scale 5000g x 0.01g. The freshly harvested above ground potion was weighed to determine the fresh weight after which the plant was oven-dried at 60 °C for 72 hours and reweighed to obtain the dry plant biomass. Same was done for the below plant biomass.

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3.7.1.9 Days to Flowering (DTF)

The number of days taken for the plants to start flowering was counted and recorded.



Plate 4: Sign of flowering of the *Heliconia psittacorum* plant.

3.7.2 Data on Vase Life Studies

Temperature and relative humidity in the storage room were recorded daily, whereas that of the CO_2 chamber was recorded on days 0 and 7. Visual appearance was assessed on every third day, whereas Fresh weight loss and vase solution uptake were recorded on days 7 and 14.

3.7.2.1 Fresh weight loss (FWL) in (grams)

The weights of the cut flower stems were measured in grams each time it was taken out before immersing them again into their holding solutions. This was done on days 0, 7, and 14 using KERN TEE 150-1 Designer pocket balance. The initial weight of cut flower stems was

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noted as $\boldsymbol{m_1}$ on day 0 and day 7, and the final weight on day 7 and day 14 was also noted as $\boldsymbol{m_2}$. ***FWL*** by cut flowers on days 7 and 14 was calculated as = $\boldsymbol{m_1}$ - $\boldsymbol{m_2}$.



Plate 5: Measuring the fresh weight of cut flowers.

3.7.2.2 Visual appearance

A subjective rating scale from **I** to **IV** was used to assess flower quality:

I - Turgid flower stem and/or bract: High marketable flower

II - Onset of dried tip(s) of the bract: Good to moderate marketability

III - Loss of the stem turgor or a prominent spot on the bract: Low marketability

IV - Discoloration or darkening of the flower stem and/or bract: Not marketable

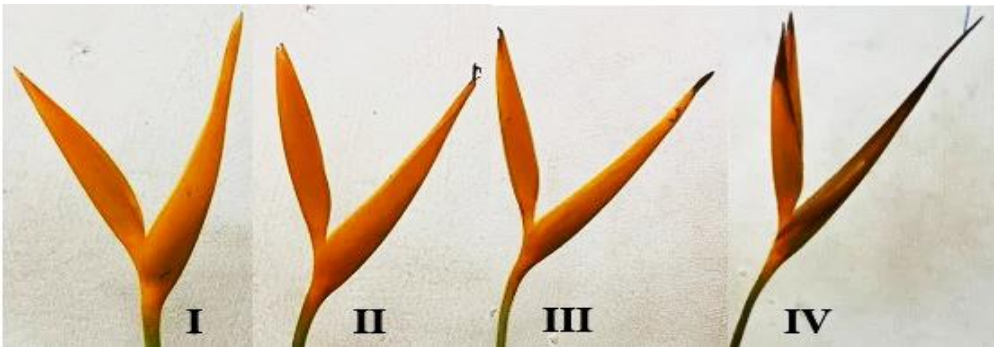


Plate 6:Visual rating scale for flower quality.

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3.7.2.4 Flower Longevity (FL) in days

This was measured starting from the day the cut flower stems were placed in the preservative solutions to the day it was noticed that the flowers had lost their ornamental or display value (colour change, wilting, and loss of turgidity) (Asrar, 2012) attaining a score of IV (Plate 9), which is an unsatisfactory marketable flower. Estimating longevity, the number of inflorescences with visual appearance rates higher than or equal to IV was taken into account for the first 14 days following harvest.

3.7.2.5 Mean Temperature and Relative humidity (RH) of Storage room

Storage room temperature and relative humidity were recorded daily throughout the vase life period using a datalogger TemLog 20H model, with serial number HM1190400087.

3.7.2.6 Carbon dioxide concentration, Temperature and R.H in CO_2 chamber

The amount of CO_2 released by the cut flowers at a prevailing temperature and relative humidity were recorded in an enclosed and airtight chamber at two minutes interval for ten minutes using an Air Quality Monitoring Instrument, I Q Air brand, model - Air Visual Pro. This was repeated on day 7 after recutting of flower stems and renewal of vase solutions.



Plate 7: Measuring CO_2 released by cut flowers.

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3.8 Statistical analysis

Statistical analyses included analysis of variance (ANOVA) and mean separation of all dependent variables studied using Tukey‟s test and correlation analysis between substrate characteristics and the dependent variables was studied. The GenStat software program (12 edition) was used and terms were considered significant at $P \leq 0.05$.



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CHAPTER FOUR

4.0 RESULTS

4.2 Agronomic traits of *Heliconia psittacorum*

4.2.1 Effect of Substrate on Sprouting Time and Number of Sprouts per Pot

Table 4.1 presents the comparison of means for two growth parameters: sprouting time (in weeks) and number of sprouts per pot at week 50 for *Heliconia psittacorum* grown on six different substrates across two experiments.

4.2.1.1 Sprouting Time

Sprouting time was generally shortest in plants grown on decomposed oil palm stems, with mean values of 3.9 and 5.2 weeks in experiment 1 and 2 respectively. These were not significantly different from most other treatments except for the River sand + Coconut fibre treatment in experiment 1, which recorded the longest sprouting time (5.2 weeks) and was significantly different ($p \leq 0.05$) from the decomposed oil palm stems.

Variations in sprouting time for both experiments were not statistically significant across all substrates, as indicated by shared superscript letters. The variation in sprouting time for both experiments ranged from 0.3 weeks to 1.3 weeks (Decomposed oil palm stems), with no significant differences among treatments.

4.2.1.2 Number of Sprouts per pot at Week 50

There were no statistically significant differences in the number of sprouts per pot among treatments within either experiment. However, numerically, River sand + Chicken manure yielded the highest number of sprouts (8.9 and 9.7 in experiments 1 and 2, respectively), while River sand + Coconut fibre yielded the fewest in experiment 1 (5.8).

The differences in variation in the number of sprouts were generally small and not statistically significant, ranging from 0.1 to 1.1 sprouts per pot.

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The variations in number of sprouts per pot ranged from 0.1 to 1.1, with the largest numerical increase observed in the Top soil + Coconut fibre treatment, though this was not statistically significant.

Table 4.1: Means comparison of two growth parameters measured on *Heliconia psittacorum* cultivated on different substrates.

Substrate	Sprouting time			Number of sprouts per pot at week 50		
	Expt. 1	Expt. 2	Variation in Expt.	Expt. 1	Expt. 2	Variation in Expt.
DOS	3.9^{a}	5.2	1.3	6.4	7.4	1.0
TS + CM	4.2^{ab}	4.6	0.4	7.8	8.6	0.8
TS + CF	4.9^{ab}	5.2	0.3	8.6	8.5	0.1
RS + CF	5.2^{b}	4.9	0.3	5.8	6.9	1.1
RS + CM	4.8^{ab}	5.5	0.7	8.9	9.7	0.8
CS	4.6^{ab}	4.9	0.3	7.5	7.9	0.4
P value	0.031	0.399	0.327	0.210	0.054	0.193

DOS = Decomposed Oil Palm stems, TS + CM = Top soil + Chicken manure, TS + CF = Top soil + Coconut fibre, RS + CF = River sand + Coconut fibre, RS + CM = River sand + Chicken manure, CS = Clayey soil
Significance ($p \leq 0.05$)
Means with the same letter between columns are not statistically different. Tukey, $P < 0.05$.

4.2.2 Days to flowering of *Heliconia psittacorum*

The data presented in Table 4.2 show the influence of different growth media on the number of days to flowering of *Heliconia psittacorum* during experiment 2. No sign of flowering was observed on plants from all treatments in experiment one as indicated by the dashes in the corresponding column.

In experiment 2, significant differences ($p \leq 0.05$) were observed among the growth media in terms of the number of days to flowering. The medium comprising Top soil mixed with coconut fibre resulted in the earliest flowering, with plants flowering in an average of 161.0 days. This treatment was statistically different from most other media and was the only treatment

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designated with the superscript "a", indicating a significantly shorter time to flowering. The second and third earliest flowering were recorded in the media with Top soil combined with chicken manure (204.4 days) and decomposed oil palm stems (230.3 days) respectively. These media shared a common superscript "ab", signifying that they were not significantly different from each other or from some of the other treatments.

On the other hand, the longest time to flowering was observed in the control treatment (clayey soil), where plants took an average of 248.5 days to flower. This result was statistically similar to the media containing river sand and coconut fibre (242.9 days) and river sand with chicken manure (232.4 days), all of which shared the superscript "b", indicating no significant difference among them but a statistically longer time to flowering compared to the Top soil + Coconut Fibre.

Overall, the results indicate that the type of growth medium which significantly influences the days to flowering in *Heliconia psittacorum*, is organic and well-aerated media, particularly the combination of Top soil and coconut fibre, promoting earlier flowering. In contrast, the control (clayey soil) and sand-based media were less effective in reducing time to flowering.

Table 4.2: Effect of growth media on days to flowering of *Heliconia psittacorum*

Growth media	**No. of days to flowering**	
	Experiment 1	**Experiment 2**
Decomposed Oil Palm stems	-	230.3^{ab}
Top soil + Chicken manure	-	204.4^{ab}
Top soil + Coconut Fibre	-	161.0^{a}
River sand + Coconut Fibre	-	242.9^{b}
River sand + Chicken manure	-	232.4^{ab}
Clayey soil (control)	-	248.5^{b}
P value	-	0.020

Significance ($p \leq 0.05$)
Means with the same letter between columns are not statistically different. Tukey, $P < 0.05$.

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4.2.3 Stem Length Development in Experiments 1 and 2

Across experiments 1 and 2, *H. psittacorum* stem length increased steadily across all treatments, with notable variation based on soil and amendment types. In both experiments, the combination of Top soil with chicken manure (TS + CM) consistently produced the highest stem elongation reaching ~32 cm in experiment 1 and ~34 cm in experiment 2 by Week 21. Other strong performers included TS + CF and DOS, while RS + CF consistently showed the weakest growth (~27 cm in experiment 1), likely due to poor nutrient and water retention. A key growth phase occurred between Weeks 9–15, though stagnation was observed between Weeks 17–19 in RS + CF and TS + CF, suggesting temporary nutrient or moisture limitations. Overall, organic amendments, especially in Top soils, supported better growth, with slightly higher stem lengths in experiment 2 indicating potential improvements in environmental conditions or soil media quality.

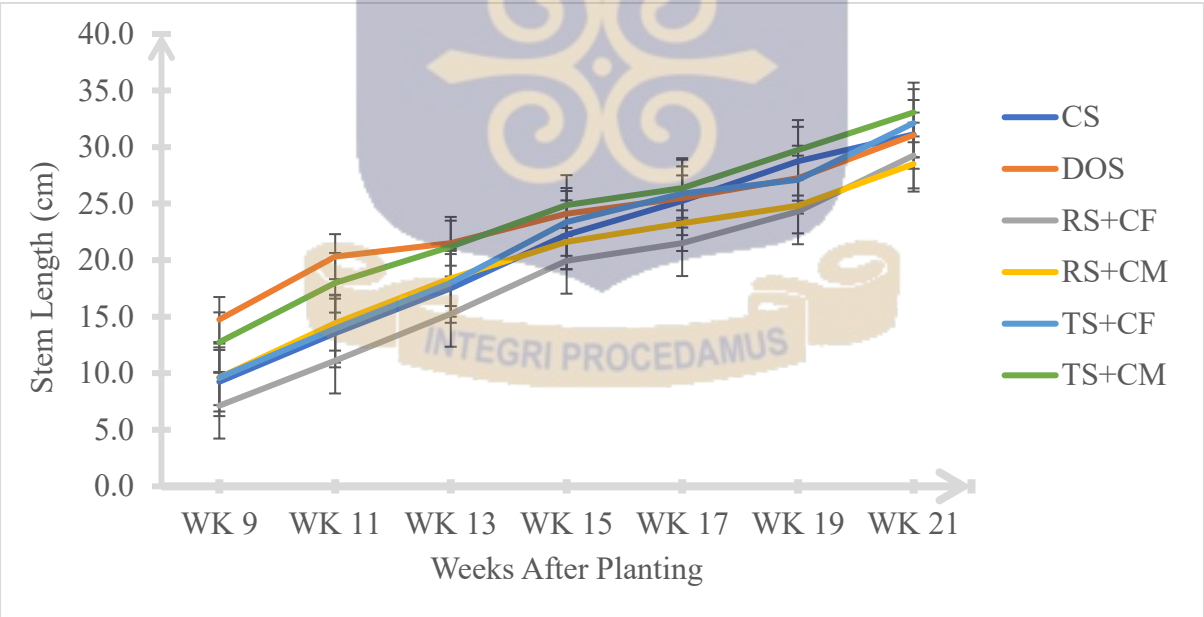


Figure 4.1: Effect of growth media on stem length development in *H. psittacorum* plants in experiment 1 (Error bars=SED).

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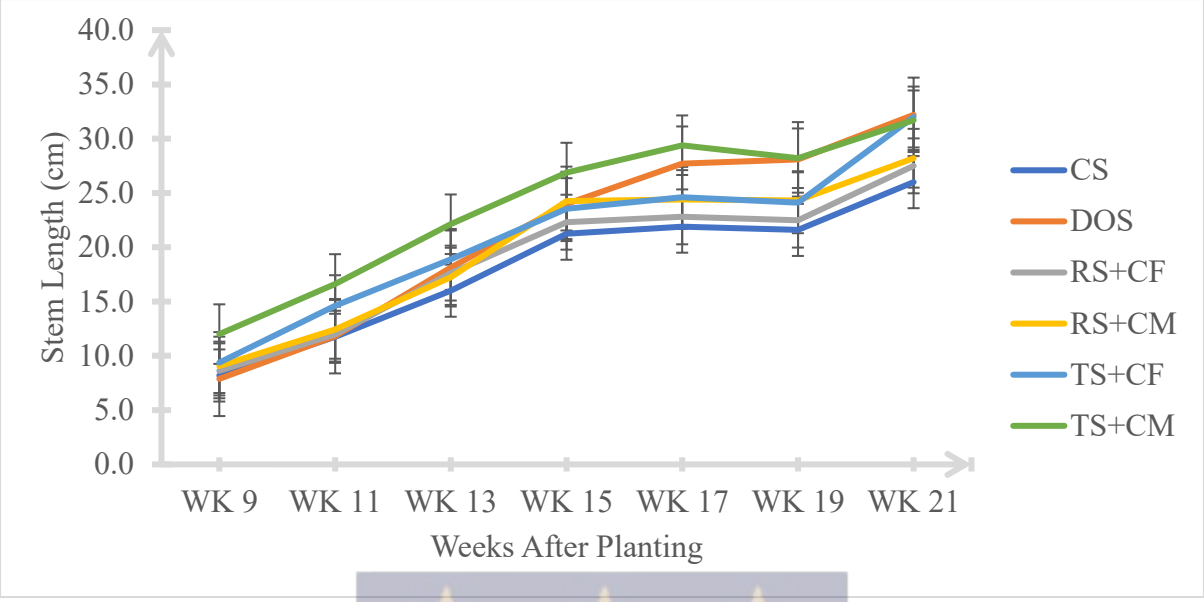


Figure 4.2: Effect of growth media on stem length development in *H. psittacorum* plants in experiment 2 (Error bars=SED).

4.2.4 Effect of Growth Media on Stem Girth Development in *Heliconia psittacorum*

Figures 4.3 and 4.4 show how the stem thickness (girth) of *Heliconia psittacorum* plants changed over time in two growing seasons using six types of soil treatments. In experiment 1, stem girth increased steadily from week 9 to week 21 in all treatments. Plants grown in DOS (Decomposed Oil Palm stems) and TS+CM (Top soil + Chicken manure) had the largest girths at week 9 (~22 mm and ~20 mm). By week 21, TS+CM had the highest girth (~50 mm), followed by TS+CF and DOS, while CS (Clayey Soil) always had the smallest girth (~15 mm at week 9 and low throughout). Treatments with organic materials (like DOS and TS+CM) helped plants grow thicker stems than those with just soil or inorganic inputs.

In experiment 2, a similar pattern was seen. All treatments showed stem growth over time, though values were slightly lower than in experiment 1. At week 9, stem girths were close (8–13 mm), but by week 15, DOS led with ~33 mm, followed by TS+CM and RS+CM (~29–30 mm). At week 21, DOS remained the highest (~40 mm), while CS stayed the lowest. Again, organic treatments like DOS and TS+CM led to better stem development.

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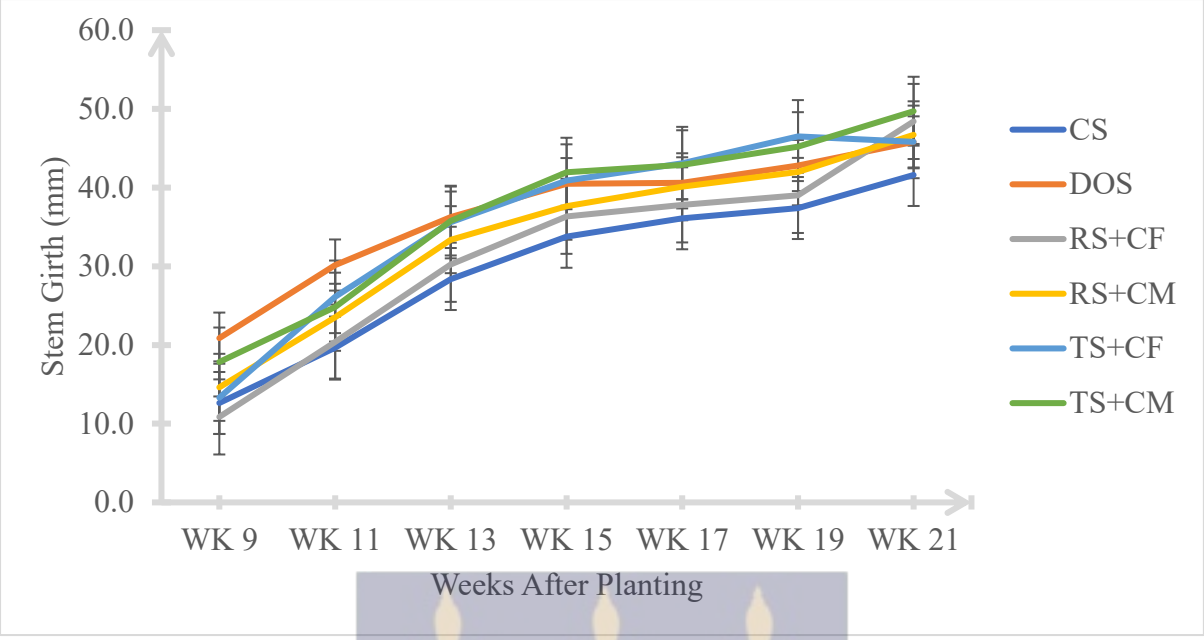


Figure 4.3: Effect of growth media on stem girth development in *H. psittacorum* plants in experiment 1 (Error bars=SED).

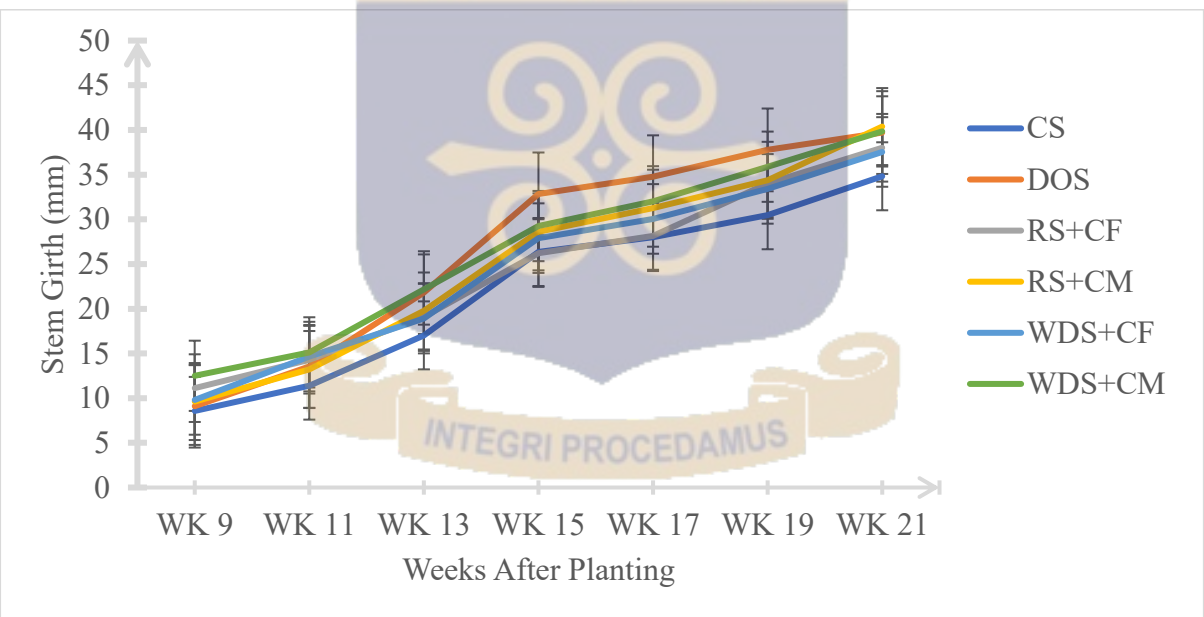


Figure 4.4: Effect of growth media on stem girth development in *H. psittacorum* plants in experiment 2 (Error bars=SED).

4.2.5 Trends in Leaf count of *Heliconia psittacorum*

In experiment 1 **(**Figure 4.5**)**, the number of leaves increased steadily across all treatments from Week 9 to Week 21. At Week 9, TS + CM recorded the highest mean leaf count (4.2), followed

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closely by DOS (4.0), while RS + CF had the lowest count (3.0). By Week 13, DOS reached a peak of approximately 6.5 leaves, outperforming other treatments at that time point. However, from Week 15 onward, TS + CM surpassed other media in leaf production, reaching 7.2 leaves by Week 21—the highest among all treatments. TS + CF also showed strong performance, ending with a mean of 7.1 leaves. In contrast, RS + CF consistently remained the least effective medium, ending with only about 6.0 leaves at Week 21.

Experiment 2 **(**Figure 4.6**)**, followed a similar trend, with all treatments showing progressive leaf development. At Week 9, TS + CM again led with a mean leaf count of 2.8, while RS + CF recorded the lowest (1.8). Leaf number increased sharply between Weeks 11 and 15 across all treatments. By Week 21, RS + CM and TS + CM recorded the highest number of leaves, approximately 8.0 and 7.8 respectively. TS + CF followed closely at around 7.5 leaves, while CS and RS + CF lagged with final counts of approximately 6.5 and 6.3, respectively. Notably, RS + CM improved significantly in experiment 2 compared to experiment 1, showing that its performance may be seasonally dependent or influenced by environmental conditions.

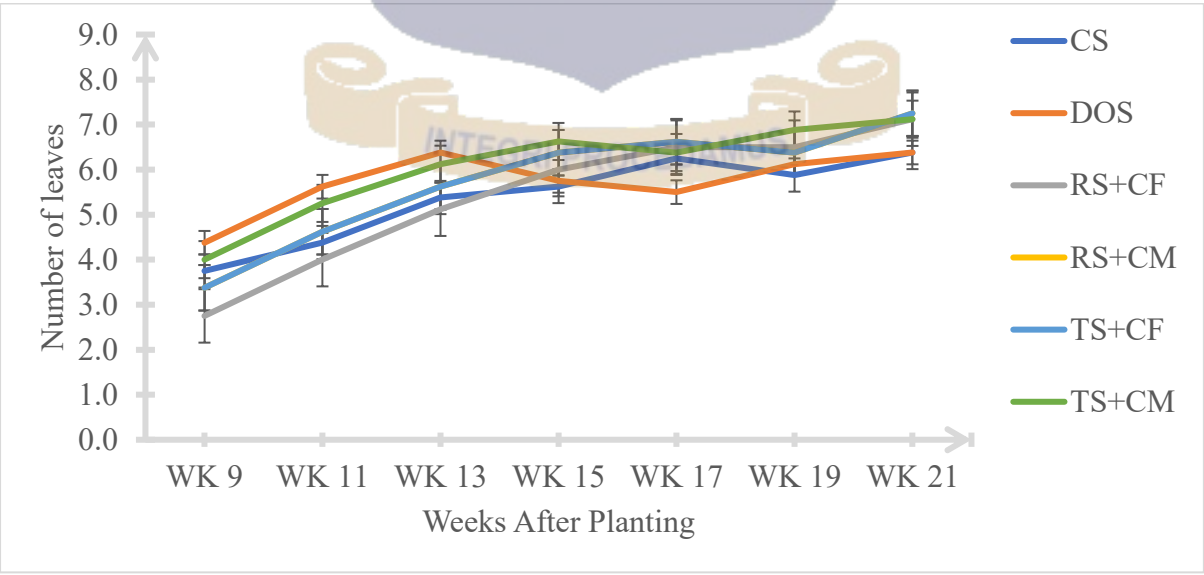


Figure 4.5: Effect of growth media on the number of leaf count of *H. psittacorum* plants in experiment 1(Error bars=SED).

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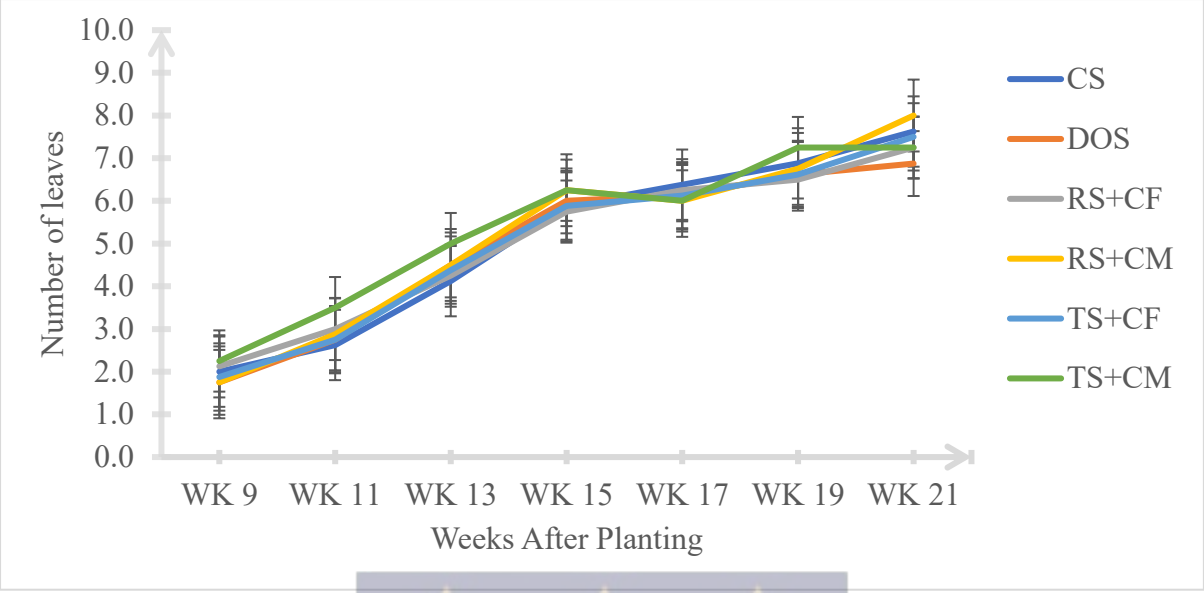


Figure 4.6: Effect of growth media on the number of leaf count of *H. psittacorum* plants in experiment 2 (Error bars=SED).

4.2.6 Effect of Growth Media on Leaf Area

Presented in Figures 4.7 and 4.8 are the effects of different growth media on the leaf area development in the *Heliconia psittacorum* plant in experiment one and two, respectively. In both seasons, plants grown in Top soil + Chicken manure consistently recorded the highest leaf area values throughout the weeks after planting (WAP), showing a steady increase from 9 to 21 WAP. This treatment showed superior performance compared to all others.

Decomposed Oil Palm stems and River sand + Chicken manure also supported considerable leaf area development, especially from 13 WAP onward, with Decomposed Oil Palm stems showing a particularly marked increase in experiment 2. In contrast, Clayey soil and River sand + Coconut fibre generally resulted in lower leaf area values, particularly during the early growth stages, though modest improvements were seen at later weeks. Top + Coconut fibre displayed moderate performance across both experiments, without achieving the highest values.

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Overall, the data from both graphs suggest that Top soil + Chicken manure is the most effective medium for promoting leaf expansion in *H. psittacorum*, likely due to its superior nutrient and moisture-retention properties.

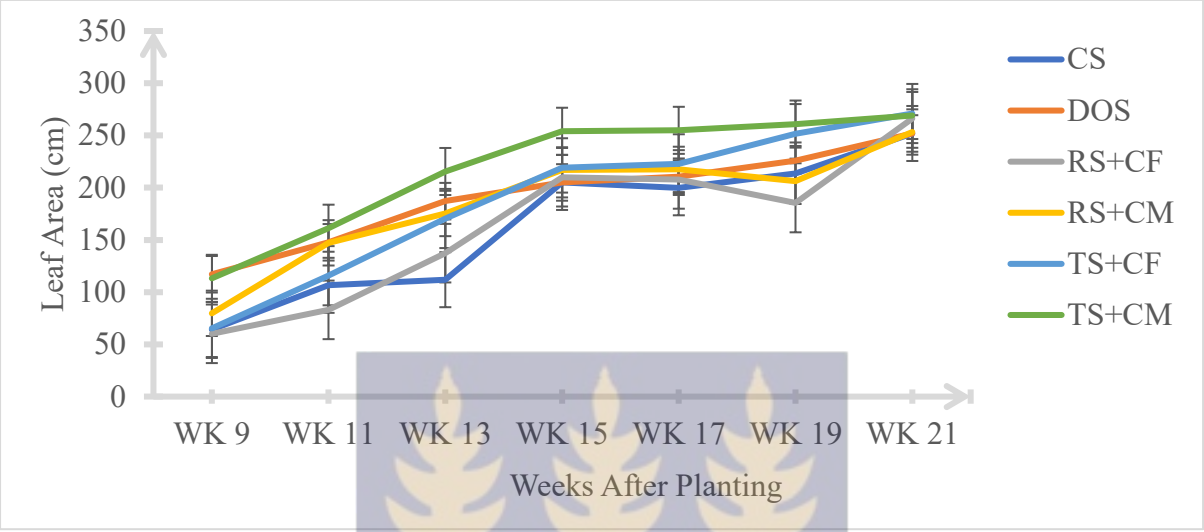


Figure 4.7: Effect of growth media on the leaf area development in *H. psittacorum* plants in experiment 1 (Error bars=SED).

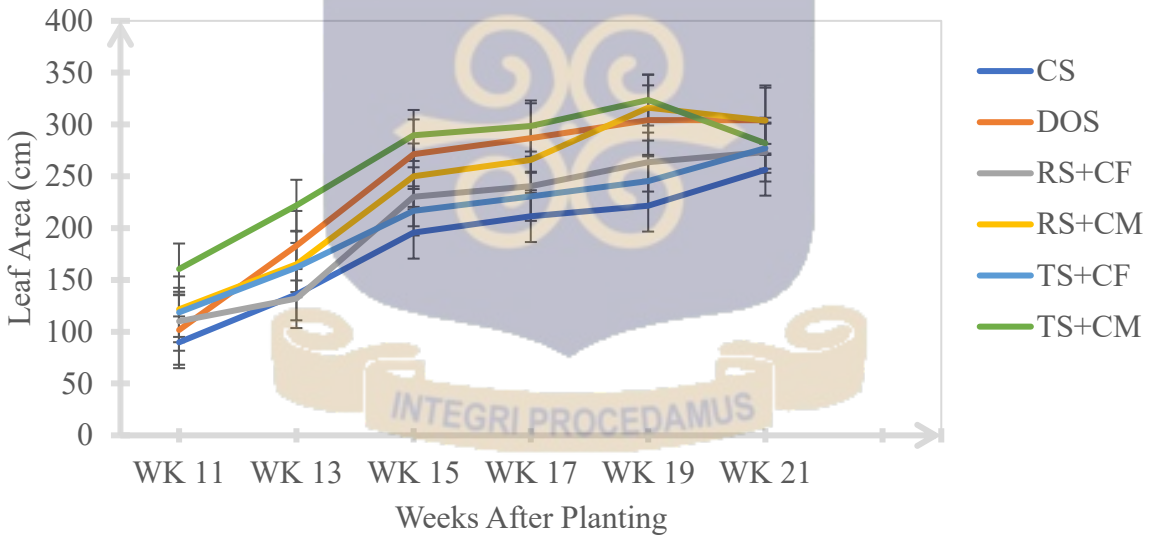


Figure 4.8: Effect of growth media on the leaf area development in *H. psittacorum* plants in experiment 2 (Error bars=SED).

4.2.7 Chlorophyll content

The effect of growth media on the trend of chlorophyll development in *Heliconia psittacorum* plants in both experiment one and experiment two is indicated in Figures 4.9 and 4.10, respectively. The chlorophyll content of plants from most of the substrates used in experiment

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one saw a sharp rise from 9 WAP to 11 WAP and then dropped rapidly from 11 WAP to 15 WAP before rising again to 19 WAP and then rose slightly towards 21 WAP. The levels of the chlorophyll content of plants varied among the different growth media as the weeks went by. No clear substrate produced plants with the highest chlorophyll content from the 9 WAP up to the 21 WAP. Plants from 'Top soil + Chicken manure' and 'River sand + Coconut Fibre' recorded the lowest chlorophyll content during the period under study (Figure 4.9).

In the second experiment, the chlorophyll content of plants for all the substrates, with the exception of 'Top soil + Chicken manure' rose from 17 WAP to its peak at 19 WAP before falling at 21 WAP. The highest chlorophyll content of plants with 'Top soil + Chicken manure' as substrate was recorded at 11 WAP and this began to drop until 21 WAP (Figure 4.10).

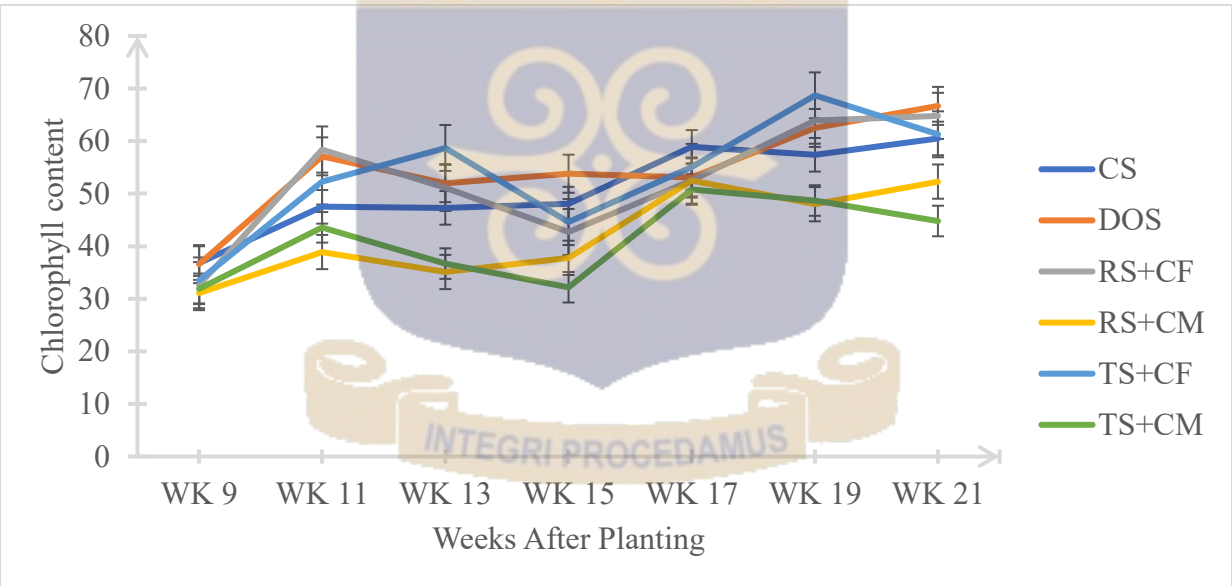


Figure 4.9: Effect of growth media on the chlorophyll content development in *H. psittacorum* plants in experiment 1 (Error bars=SED).

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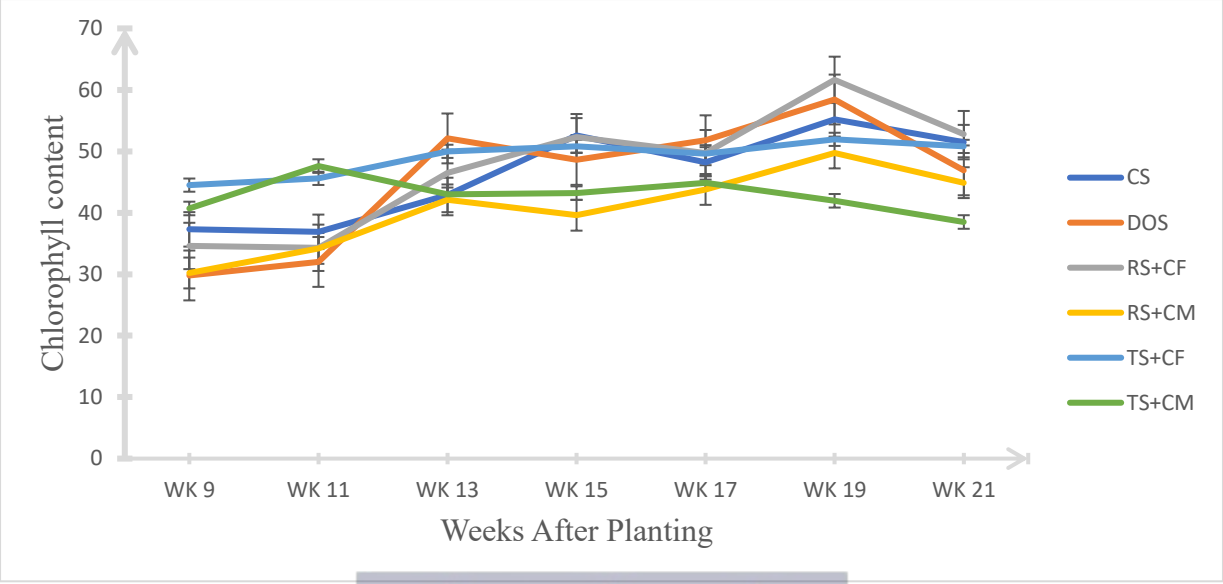


Figure 4.10: Effect of growth media on the chlorophyll content development in *H. psittacorum* plants in experiment 2 (Error bars=SED).

4.2.9 Effect of Growth Media on Plant Biomass at 50 Weeks After Planting

The study evaluated the effect of different growth media on plant biomass (fresh and dry shoot and root biomass) 50 weeks after planting over two experiments. While most treatments showed no statistically significant differences ($p \leq 0.05$), some distinctions were observed in experiment 1.

In experiment 1, clayey soil (CS) produced significantly the highest fresh (176.3 g) and dry shoot biomass (50.38 g) compared to all other treatments. Other treatments such as TS + CM, RS + CM, RS + CF, and TS + CF had statistically similar shoot biomass to each other and to the DOS control. Root biomass values varied numerically, with DOS highest in fresh root biomass (81.7 g) and TS + CF the lowest (48.93 g), but these differences were not statistically significant.

In experiment 2, no significant differences were found across treatments for any biomass type. CS again showed the highest numerical values for fresh shoot (117.3 g), fresh root (44.25 g), and dry root biomass (19.65 g), while DOS generally recorded the lowest.

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Table 4.3: Effect of growth media on plant biomass at 50 weeks after planting

Growth media	Season 1				Season 2			
	Fresh shoot biomass	Dry shoot biomass	Fresh root biomass	Dry root biomass	Fresh shoot biomass	Dry shoot biomass	Fresh root biomass	Dry root biomass
DOS	117.4^{a}	27.00^{a}	81.70	20.68	91.3	26.35	40.27	12.08
TS + CM	144.0^{ab}	34.52^{ab}	64.05	26.65	117.1	26.55	42.00	14.80
TS + CF	128.2^{ab}	31.75^{a}	48.93	17.85	93.3	22.15	34.75	12.93
RS + CF	130.2^{ab}	32.52^{a}	74.80	23.27	104.3	30.32	35.85	14.10
RS + CM	133.1^{ab}	29.10^{a}	64.50	14.60	108.7	28.40	39.00	12.75
CS	176.3^{b}	50.38^{b}	50.75	23.07	117.3	29.45	44.25	19.65
P value	0.031	0.006	0.651	0.651	0.543	0.470	0.891	0.140

DOS = Decomposed Oil Palm stems, TS + CM = Top soil + Chicken manure, TS + CF = Top soil + Coconut fibre, RS + CF = River sand + Coconut fibre, RS + CM = River sand + Chicken manure, CS = Clayey soil
Significance ($p \leq 0.05$)
Means with the same letter between columns are not statistically different. Tukey, $P < 0.05$.

4.2.10 Character association of ten agronomic traits of *Heliconia psittacorum*

The linear relationships among ten key agronomic traits of *Heliconia psittacorum* across two experiments were analysed. In experiment 1, correlations were generally weak, though some positive associations were observed, notably between the number of leaves and leaf area (r = 0.57), and between shoot girth and both shoot height (r = 0.56) and number of leaves (r = 0.71). Negative correlations included the number of suckers with chlorophyll content (r = -0.37) and fresh root biomass (r = -0.29), suggesting a potential competition for resources. Most biomass traits exhibited weak associations (r < 0.3). In contrast, experiment 2 showed stronger and more structured relationships. Notable positive correlations included dry and fresh root biomass (r = 0.84), dry and fresh shoot biomass (r = 0.80), and flower weight with shoot biomass and height (r = 0.50–0.41). Negative relationships were seen between leaf area and

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chlorophyll content (r = -0.45), and again between sucker number and various biomass traits. Comparison between experiments revealed clearer, more biologically meaningful correlations in experiment 2, likely due to better growth conditions. Across both seasons, shoot girth and height consistently correlated with biomass traits, marking them as indicators of plant vigour, while sucker production remained negatively associated with key growth and biomass parameters, highlighting an underlying competition in resource allocation.

Table 4.4: Correlation among ten agronomic parameters of *H. psittacorum* in season 1

CC_21 WAP	-									
DRB_50 WAP	-0.08	-								
DSB_50 WAP	0.04	0.29	-							
FRB_50 WAP	0.11	0.82	0.08	-						
LA_21 WAP	-0.17	0.24	0.24	0.29	-					
NOL_21 WAP	-0.03	0.04	0.22	-0.11	0.57	-				
NOS_50 WAP	-0.37	-0.20	-0.26	-0.29	0.13	0.20	-			
SG_21 WAP	-0.08	0.14	0.25	0.06	0.44	0.71	-0.08	-		
SL_21 WAP	-0.12	0.27	0.42	0.23	0.33	0.43	-0.24	0.55	-	
WS	-0.04	-0.06	-0.01	-0.11	0.26	0.05	0.33	-0.05	-0.36	-
	CC_21 WAP	**DRB_50 WAP**	**DSB_50 WAP**	**FRB_50 WAP**	**LA_21 WAP**	**NOL_21 WAP**	**NS_50 WAP**	**SG_21 WAP**	**SH_21 WAP**	**WTS**

CC_21 WAP = Chlorophyll Content at 21 Weeks After Planting
DRB_50 WAP = Dry Root Biomass at 50 Weeks After Planting
DSB_50 WAP = Dry Shoot Biomass at 50 Weeks After Planting
FRB_50 WAP = Fresh Root Biomass at 50 Weeks After Planting
LA_21 WAP = Leaf Area at 21 Weeks After Planting
NOL_21 WAP = Number of Leaves at 21 Weeks After Planting
NOS_50 WAP = Number of Sprouts at 50 Weeks After Planting
SG_21 WAP = Stem Girth at 21 Weeks After Planting
SL_21 WAP = Stem Length at 21 Weeks After Planting
WTS = Weeks to Sprouting

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Table 4.5: Correlation among ten agronomic parameters of *H. psittacorum* in season 2

	CC_21 WAP	DRB_50 WAP	DSB_50 WAP	FRB_50 WAP	LA_21 WAP	NOL_21 WAP	NOS_50 WAP	SG_21 WAP	SL_21 WAP	WTS	WTF
CC_21 WAP	-										
DRB_50 WAP	0.10	-									
DSB_50 WAP	0.09	0.42	-								
FRB_50 WAP	-0.21	0.84	0.44	-							
LA_21 WAP	-0.45	-0.04	0.03	0.30	-						
NOL_21 WAP	-0.25	0.29	0.00	0.30	0.22	-					
NOS_50 WAP	-0.32	-0.22	-0.24	-0.09	-0.07	0.49	-				
SG_21 WAP	-0.38	-0.02	-0.03	0.30	0.42	0.15	0.29	-			
SL_21 WAP	-0.28	0.05	0.06	0.32	0.58	-0.12	-0.02	0.29	-		
WTS	0.10	-0.49	-0.25	-0.43	0.06	0.01	0.06	-0.13	-0.18	-	
WTF_	-0.24	0.01	0.50	0.15	0.34	0.23	0.18	0.41	-0.01	0.03	-

DRB_50 WAP = Dry Root Biomass at 50 Weeks After Planting
DSB_50 WAP = Dry Shoot Biomass at 50 Weeks After Planting
FRB_50 WAP = Fresh Root Biomass at 50 Weeks After Planting
LA_21 WAP = Leaf Area at 21 Weeks After Planting
NL_21 WAP = Number of Leaves at 21 Weeks After Planting
NOS_50 WAP = Number of Sprouts at 50 Weeks After Planting
SG_21 WAP = Stem Girth at 21 Weeks After Planting
SL_21 WAP = Stem Length at 21 Weeks After Planting
WTS = Weeks to Sprouting

4.3 Vase Life Studies

4.3.1 Fresh Weight Loss (FWL) of Cut Flower Stems in Preservative Solutions

Table 4.11 presents the mean fresh weight loss of cut *Heliconia* flowers in response to varying sucrose concentrations in vase solutions, measured at 7 and 14 Days In Preservation (DIP) across two experimental runs.

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At **7** DIP, fresh weight loss ranged from 1.7 g to 3.0 g, with no statistically significant differences observed among treatments ($P > 0.05$) in both Experiment 1 and Experiment 2. This suggests that within the first week of vase life, sucrose concentration had a limited impact on water balance and subsequent fresh weight loss.

At 14 DIP, however, more pronounced differences emerged, particularly in Experiment 1 where the 10% sucrose treatment resulted in the highest weight loss (7.0 g), significantly different from the control (4.2 g) and the 15% treatment (4.7 g), with a P-value of 0.018, indicating a statistically significant difference ($P \leq 0.05$). This might suggest that while moderate sucrose concentrations can help maintain turgor initially, excess sucrose (in this case, 10%) may lead to osmotic imbalances or microbial growth that accelerates water loss over time.

In contrast, the same trend was not observed in Experiment 2 at 14 DIP, where the P-value of **0.**284 indicates no significant differences across treatments. The variation between experiments could be attributed to environmental conditions, batch variability of flowers, or microbial differences in water quality or handling practices.

The differences in variation across experiments were also minimal and statistically non-significant, further emphasizing consistency in treatment response but also suggesting external uncontrolled factors may have influenced the longer-term water balance of the cut stems.

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Table 4.6: Mean Fresh Weight Loss (g) of Cut Heliconia Flowers in Different Vase Solutions

Sucrose Concentration	7 DIP in Exp. 1	7 DIP in Exp. 2	Difference in variation	14 DIP in Exp. 1	14 DIP in Exp. 2	Difference in variation
0	1.9	1.7	0.2	4.2^{a}	3.7	0.5
10%	2.9	2.2	0.7	7.0^{b}	4.8	2.2
15%	3.0	2.6	0.4	4.7^{a}	5.0	0.3
20%	2.9	3.0	0.1	5.1^{ab}	7.0	1.9
P value	0.057	0.713	0.423	0.018	0.284	0.566

DIP = Days In Preservation
Significance ($p \leq 0.05$)
Means with the same letter between columns are not statistically different. Tukey, $P < 0.05$.

4.3.2 Vase Solution Uptake (VSU) in (mls) by Cut Heliconia Flowers stored in varying preservative Solutions

The study summarized in Table 4.7 examined the vase solution uptake of cut Heliconia flowers treated with varying sucrose concentrations (0%, 10%, 15%, and 20%) over two experimental runs. At 7 DIP, the control group (0% sucrose) showed the highest uptake in Experiment 1 (10.8 mL), significantly surpassing all sucrose-treated groups. However, in Experiment 2, no significant differences were observed among treatments, with uptake values between 5.9 and 7.1 mL. The largest discrepancy between experiments at this stage was seen in the 0% treatment (4.9 mL), while the 10% sucrose group showed the least variation (0.7 mL).

By 14 DIP, uptake declined across all treatments. The 0% sucrose group continued to show the highest uptake in both experiments (5.3 mL and 3.1 mL), again significantly greater than sucrose-treated groups, which ranged from 1.4 to 2.2 mL. Variation between experiments narrowed at this stage, with the no difference noted in the 15% sucrose group (0.0 mL).

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Overall, the control (0% sucrose) consistently recorded the highest vase solution uptake in both experiments, indicating that sucrose addition did not enhance, and may have hindered, water uptake potentially due to osmotic stress or microbial growth.

Table 4.7: Mean vase solution uptake (mL) of Cut Heliconia Flowers in Different Vase Solutions

Sucrose Concentration	7 DIP in Exp. 1	7 DIP in Exp. 2	Difference in variation	14 DIP in Exp. 1	14 DIP in Exp. 2	Difference in variation
0	10.8^{a}	5.9	4.9	5.3^{a}	3.1	2.2^{a}
10%	6.0^{b}	6.7	0.7	2.2^{b}	1.4	0.8^{ab}
15%	5.4^{b}	6.3	0.9	2.1^{b}	2.1	0.0^{b}
20%	3.7^{b}	7.1	3.4	2.2^{b}	1.4	0.8^{ab}
P value	<.001	0.885	0.153	0.009	0.260	0.049

DAP = Days In Preservation
Significance ($p \leq 0.05$)
Means with the same letter between columns are not statistically different. Tukey, $P < 0.05$.

4.3.3: Storage Room Environment (Temperature and Relative Humidity)

Over a 14-day vase life period, temperature and relative humidity (R.H) were monitored daily in the storage room for Heliconia cut flowers kept in various preservative solutions, as shown in Figures 4.10 and 4.11 for Experiments 1 and 2, respectively. In Experiment 1, temperature remained relatively stable, fluctuating slightly between 27°C and 29.5°C, while R.H ranged from 76% to 81%. A minor dip in both parameters was observed on Day 8, indicating a brief environmental fluctuation, though overall conditions remained stable. Similarly, in Experiment 2, temperature ranged consistently between 26°C and 28°C, and R.H varied between 77% and

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83%. Despite minor daily changes, the environmental conditions in both experiments were well-controlled, minimizing external effects on the vase life of the flowers.

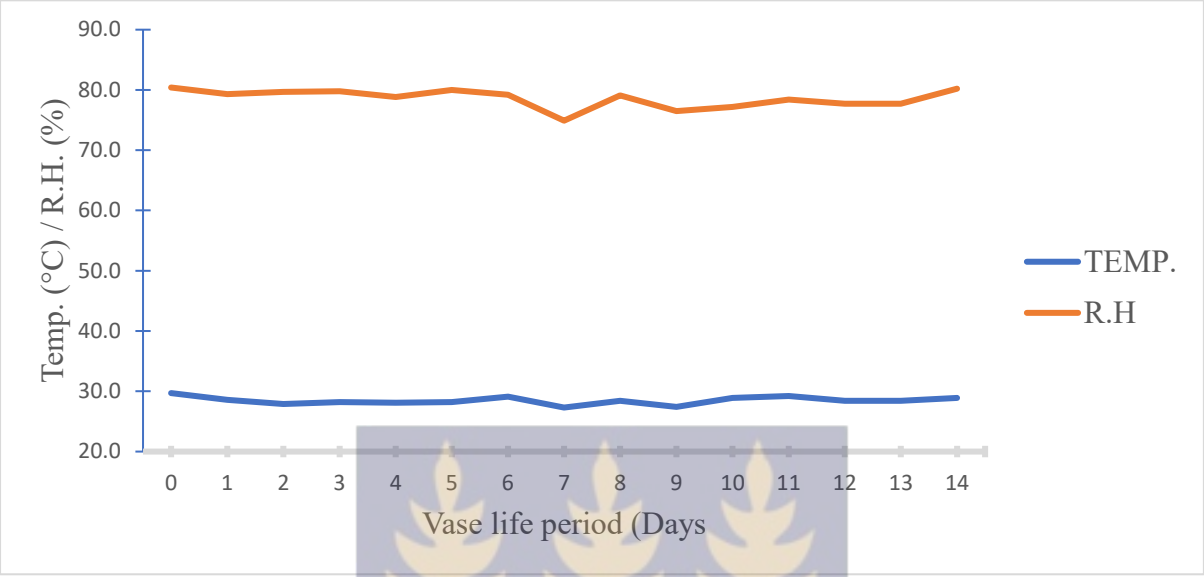


Figure 4.11: Temperature and Relative Humidity Trends in Storage Room During Vase Life during Experiment 1

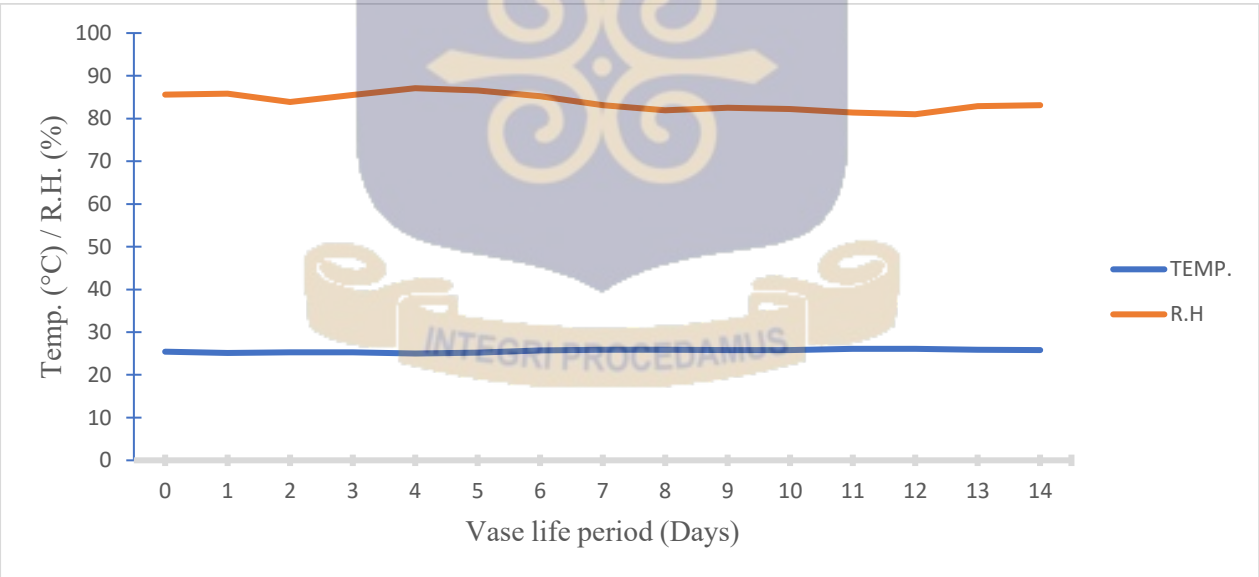


Figure 4.12: Temperature and Relative Humidity Trends in Storage Room During Vase Life during Experiment 2.

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4.3.4 Effect of Preservative Solutions on Vase Life of Heliconia Cut Flowers

Table 4.7 presents the mean vase life of *Heliconia psittacorum* stems treated with various sucrose concentrations across two independent experiments, emphasizing the impact of sucrose on postharvest longevity and the consistency of results. In Experiment 1, the control (0% sucrose) yielded the longest vase life at 14.0 days, significantly outperforming all sucrose treatments ($p \leq 0.05$). The 15% sucrose solution followed with 13.3 days, while 20% and 10% treatments averaged 12.8 and 12.1 days, respectively. However, in Experiment 2, no significant differences were observed among treatments, with vase life ranging narrowly from 12.2 to 13.3 days. Here, the 10% sucrose solution slightly outperformed others at 13.3 days, though without statistical significance.

Overall, while the control extended vase life in Experiment 1, sucrose supplementation showed inconsistent results, indicating limited reliability as a postharvest treatment for this species and underscoring the necessity of experimental replication.

Table 4.8: Mean Vase Life (Days) of *Heliconia psittacorum* in Various Preservative Solutions

Sucrose Concentration	**Experiment 1**	**Experiment 2**	**Difference in variation**
0	14.0^{a}	12.6	1.4
10%	12.1^{b}	13.3	1.2
15%	13.3^{c}	12.7	0.6
20%	12.8^{d}	12.2	0.6
P value	<.001	0.770	0.965

DAP = Days after preservation
Significance ($p \leq 0.05$)
Means with the same letter between columns are not statistically different. Tukey, $P < 0.05$.

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4.3.5 Respiration Rate of Cut Flowers Stored in Different Vase Solutions

In both Experiment 1 and Experiment 2, the effects of varying sucrose concentrations on the respiratory activity of *Heliconia* cut flowers were assessed by monitoring CO_2 release over a 10-minute period on Day 0 and Day 7. At Day 0 in both experiments, the 20% sucrose treatment (T4) consistently showed the highest CO_2 emissions, peaking around 850 ppm, indicating elevated metabolic activity. In contrast, flowers in distilled water (T1) exhibited the lowest CO_2 levels, steadily declining over time. Treatments with 10% (T2) and 15% (T3) sucrose showed intermediate and relatively stable CO_2 outputs, suggesting moderate sucrose concentrations initially moderated respiration more effectively than either extreme. By Day 7, CO_2 levels in T4 declined, indicating a waning metabolic effect, while T2 displayed increased CO_2 release, suggesting a delayed stimulatory impact. T3 remained relatively stable, and T1 showed minimal change throughout. These patterns, confirmed across both experiments, indicate that while high sucrose induces a strong but short-lived respiratory boost, moderate sucrose concentrations, particularly 10%, may better support sustained metabolic activity in *Heliconia* flowers over time.

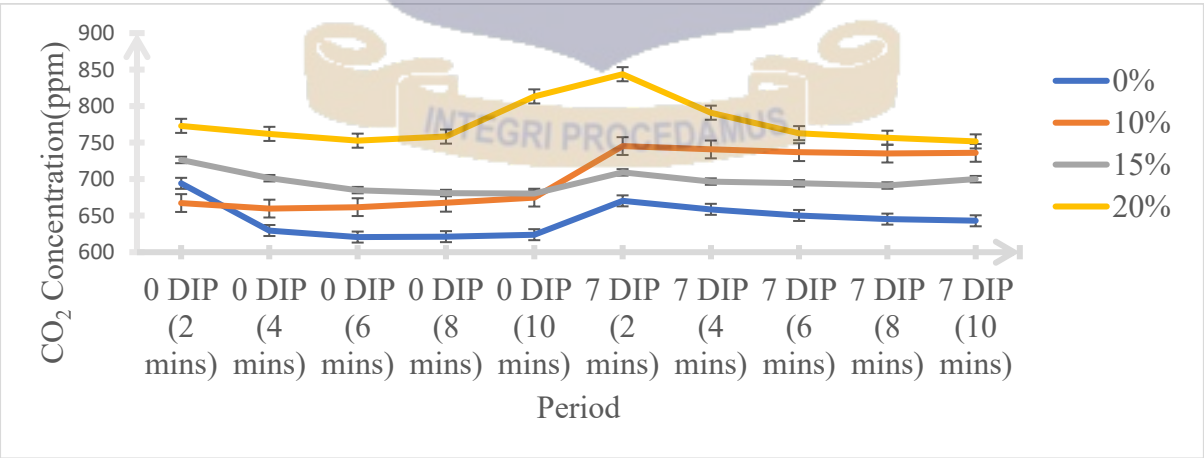


Figure 4.13: CO_2 Released by Heliconia Cut Flowers stored in different sucrose concentrations at Day 0 and Day 7 in Experiment 1(Error bars = SED).

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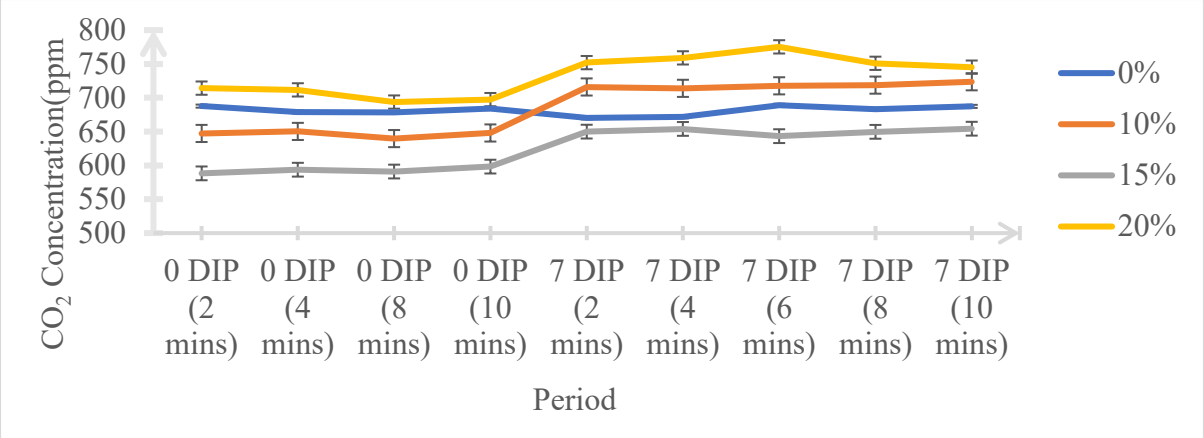


Figure 4.14: CO_2 Released by Heliconia Cut Flowers stored in different sucrose concentrations at Day 0 and Day 7 in Experiment 2 (Error bars = SED).

4.3.6 Visual Quality Assessment of Cut Flowers in Various Preservative Solutions

Table 4.9 summarizes the visual ratings of cut Heliconia flowers treated with varying sucrose concentrations (0%, 10%, 15%, and 20%) over two experiments, using a 1–4 scale where 1 indicates high marketability and 4 indicates no marketability. In experiment 1 (plate 8), flowers in 10% sucrose had the poorest appearance (score of 4), while those in 0% scored better (2), and both 15% and 20% treatments scored 3, indicating moderate quality. In experiment 2 (plate 8), the 10% sucrose treatment improved to a score of 2, while the 0% declined to 3, and the 15% and 20% treatments remained unchanged at 3. The "Difference in Variations" column revealed that 15% and 20% sucrose maintained consistent visual ratings across seasons, while the 0% and 10% treatments showed variability, with differences of 1 and 2 points, respectively. Overall, 15% and 20% sucrose solutions provided more stable preservation, though with only moderate marketability, whereas 0% and 10% solutions demonstrated greater seasonal variability, suggesting a need for further study on their efficacy.

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Table 4.9: Visual Ratings and Corresponding Scores of Cut Heliconia Flowers in Preservative Solutions

Sucrose concentration	Season 1	Season 2	Difference in variations
0%	2^a	3^a	1^a
10%	4^b	2^a	2^b
15%	3^c	3^a	0^c
20%	3^c	3^a	0^c
P value	<.001	0.112	0.025

Visual Appearance Rating Scale
1 - Turgid flower stem and/or bract: High marketable flower
2 - Onset of dried tip(s) of the bract: Good to moderate marketability
3 - Loss of the stem turgor or a prominent spot on the bract: Low marketability
4 - Discoloration or darkening of the flower stem and/or bract: Not marketable
Significance ($p \leq 0.05$)
Means with the same letter between columns are not statistically different. Tukey, $P < 0.05$.

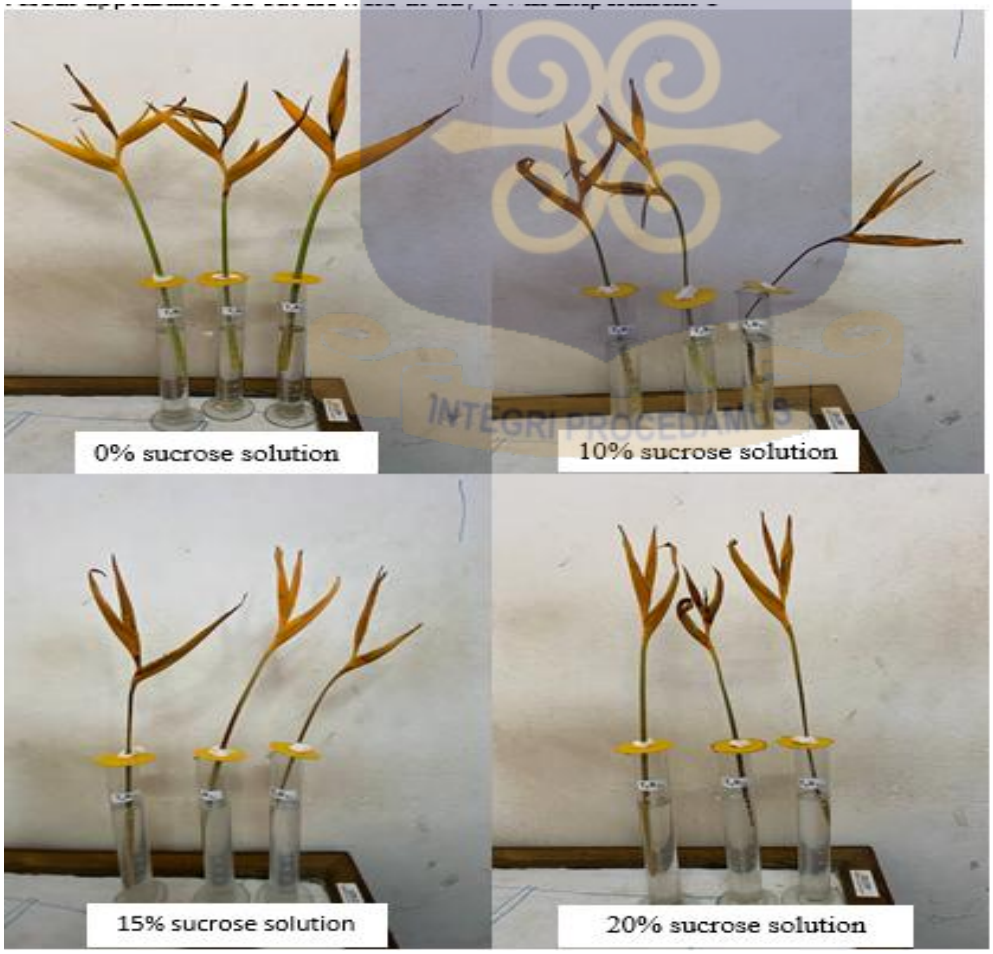


Plate 8: Visual appearance of cut flowers at day 14 in Experiment 1

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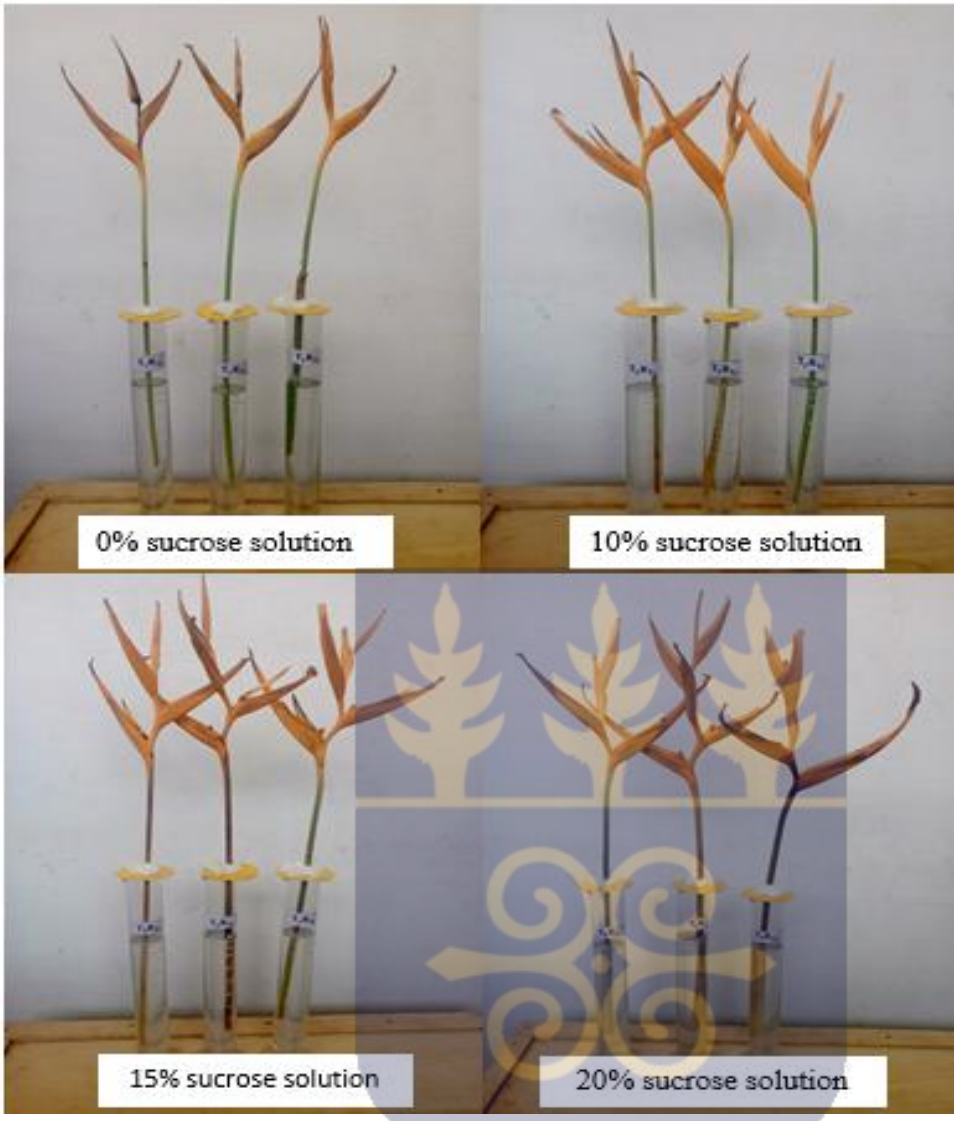


Plate 9: Visual appearance of cut flowers at day 14 in Experiment 2

4.3.7 Correlation among vase life parameters of *Heliconia psittacorum* cut flowers

Chapter 4 presents a correlation analysis of vase life parameters, highlighting distinct patterns between two experiments. In Experiment **1**, strong and moderate correlations were found between variables. Notably, FWL_14DIP had a strong negative correlation with vase life **(**r = -0.74), indicating that greater fresh weight loss by day 14 reduced longevity. Similarly, FWL_7DIP was moderately negatively correlated with vase life (r = -0.52). Conversely, vase solution uptake had a strong positive relationship with vase life, with VSU_7DIP (r = 0.65) and VSU_14DIP (r = 0.64) suggesting better hydration supports extended flower life. Additionally,

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VSU_7DIP and VSU_14DIP were strongly interrelated (r = 0.72) and both negatively correlated with early weight loss, reinforcing the link between water uptake and reduced deterioration.

In contrast, Experiment 2 showed weaker and inconsistent correlations. FWL_14DIP had only a weak negative correlation with vase life (r = -0.23), and unexpectedly, FWL_7DIP was weakly positively correlated (r = 0.27). More strikingly, VSU_7DIP was positively correlated with both FWL_7DIP (r = 0.79) and FWL_14DIP (r = 0.70), suggesting that greater water uptake coincided with more weight loss—contradicting findings from Experiment 1. VSU_7DIP showed virtually no correlation with vase life (r = -0.0098), while VSU_14DIP was weakly negative (r = -0.29).

These contrasting results suggest that Experiment 1 more clearly supports the hypothesis that improved water uptake enhances vase life and reduces weight loss, while Experiment 2's ambiguous trends may reflect differing external conditions or treatment effects, underscoring the complexity of postharvest flower.

Table 4.10: Correlation (r) coefficient of five vase life parameters in experiment 1

	FWL_7DIP	FWL_14DIP	VL	VSU_7DIP	VSU_14DIP
FWL_7DAP	-				
FWL_14DAP	0.47	-			
VL	-0.52	-0.74	-		
VSU_7DAP	-0.65	-0.22	0.65	-	
VSU_14DAP	-0.65	-0.45	0.64	0.72	-

FWL_7DIP Fresh Weight Loss_ 7 Days In Preservation
FWL_14DIP Fresh Weight Loss_ 14 Days In Preservation
VL Vase Life
VSU_7DIP Vase Solution Uptake_7 Days In Preservation
VSU_14DIP Vase Solution Uptake_14 Days In Preservation

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Table 4.11: Correlation (r) coefficient of five vase life parameters in experiment 2

	FWL_7DIP	FWL_14DIP	VL	VSU_7DIP	VSU_14DIP
FWL_7DIP	-				
FWL_14DIP	0.52	-			
VL	0.27	-0.23	-		
VSU_7DIP	0.79	0.70	-0.01	-	
VSU_14DIP	0.15	-0.15	-0.29	0.01	-

FWL_7DIP Fresh Weight Loss_ 7 Days In Preservation
FWL_14DIP Fresh Weight Loss_ 14 Days In Preservation
VL Vase Life
VSU_7DIP Vase Solution Uptake_7 Days In Preservation
VSU_14DIP Vase Solution Uptake_14 Days In Preservation

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CHAPTER FIVE

5.0 DISCUSSION

The variation in the sprouting time of *Heliconia psittacorum* across different growth media and experiments is consistent with recent research underscoring the role of substrate composition and environmental conditions in plant propagation. Experiment 1 showed faster sprouting in decomposed oil palm stems, attributed to enhanced nutrient supply and moisture retention, a result that supports Ahmad et al. (2021), who found that substrates rich in organic matter promote faster sprouting due to increased microbial activity. Similarly, Top soil with chicken manure expedited sprouting, aligning with Singh and Kumar (2023), who reported that organic amendments improve soil fertility and water retention. However, delayed sprouting in decomposed oil palm stems during experiment 2 may result from seasonal changes affecting decomposition and nutrient release, as suggested by Chen et al. (2020). The contrasting performance of river sand and coconut fibre between the two experiments reflects the influence of aeration and drainage properties interacting with seasonal conditions, as noted by Lopez et al. (2019). These findings underscore the need to tailor propagation media according to seasonal dynamics.

Organic amendments like chicken manure and coconut fibre consistently enhance *Heliconia* performance. For instance, in *Calycophyllum spruceanum*, chicken manure-rich substrates increased chlorophyll and nitrogen levels (Guerra-Arévalo et al., 2025). In this study, river sand + chicken manure yielded the highest sprout numbers (8.9 and 9.7 at 50 WAP), showing the benefits of nutrient-rich media. Olaria et al. (2016) found similar results with cattle manure and coconut husk but noted poor results with chicken bedding due to high electrical conductivity. These findings show that while organic materials improve sprouting, not all amendments are equally beneficial. Dos Santos et al. (2016) also observed poor seedling quality with chicken bedding, echoing the low performance of coconut fibre + sand here. These

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contradictions highlight the importance of evaluating each amendment's specific qualities. Experimental consistency and higher performance in experiment 2 further affirm Pereira (2025) and Kamp (2005)'s emphasis on consistent nutrient supply and physical properties. Future studies should differentiate between high-quality organic inputs and those that may introduce stress factors like salinity.

Substrate properties strongly affect the flowering timeline of *Heliconia*. Studies by Linares Gabriel et al. (2019) and Malakar & Biswas (2020) show that nutrient-rich, decomposable media hasten flowering. This is supported by the current finding that decomposed oil palm stems triggered the earliest flowering at 16 weeks, due to sustained nutrient release and good water retention. Clayey soil, which saw flowering at 18 weeks, performed as expected due to its moderate fertility. In contrast, media with poor organic content and water retention, like river sand + coconut fibre, delayed or inhibited flowering. According to Souza et al. (2020) and Carrera Alvarado et al. (2021), insufficient media structure and nutrient levels impede flower initiation. This explains the delayed flowering in river sand + chicken manure (33 weeks), river sand + coconut fibre (35 weeks), and the absence of flowering in loamy soil + coconut fibre. These results reinforce the role of high-quality, nutrient-rich substrates in achieving timely flowering.

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Organic-rich substrates notably improve vegetative growth in *Heliconia psittacorum*. Oliveira et al. (2024) found that combining organic materials like filter cake or compost with mineral fertilizers increased flower-stem length and pseudostem weight by enhancing soil fertility. Likewise, Roy & Kashem (2014) reported a robust seedling growth in substrates containing cattle manure and coconut husk, but poor performance in chicken bedding due to high electrical conductivity. These outcomes are mirrored here: Top soil + chicken manure produced the tallest stems (33 cm at 21 WAP), while clayey soil consistently hindered growth. Substrates

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promoting aeration and drainage, such as coconut fibre and Top soil, are linked to greater plant height, aligning with Díaz et al. (2009), who observed similar outcomes in coconut fibre media. The initially poor performance of sand + coconut fibre and clayey media is attributed to early-stage deficiencies in water and nutrients, which gradually improved matching trends in prior studies. This reinforces that substrate texture and organic quality are vital for optimizing vegetative growth.

Chicken manure-enriched media also led to increased leaf counts in *Heliconia*, paralleling Guerra Arévalo et al. (2025), who reported greater chlorophyll, nitrogen, and biomass in tree seedlings with chicken manure. Malakar et al. (2019) similarly noted improved shoot and leaf development in Heliconia with river sand, topsoil, and compost. In this study, both RS+CM and TS+CM showed higher leaf counts across seasons compared to inert media. However, decomposed oil palm stems (DOS) displayed inconsistent performance, reflecting broader patterns where organic content fluctuates. Gómez Merino et al. (2012) emphasized that precise nutrient control is essential in hydroponic Heliconia systems. Moreover, Díaz et al. (2009) found that coconut fibre similar in structure to DOS could promote excessive vegetative growth, impairing uniform leaf development. Therefore, while DOS supports growth, its variable nutrient dynamics make it less consistent than chicken manure-based amendments.

Top soil with chicken manure consistently yielded the largest leaf area in *Heliconia psittacorum*, supporting research that highlights the role of nitrogen, phosphorus, and potassium in vegetative development. Castro et al. (2015, via Linares Gabriel et al., 2019) emphasized that lacking these nutrients reduces leaf area, while Paillat et al. (2020) noted that bark or coir mixed with fertilizers enhances nutrient release through microbial action. These mechanisms explain the superior leaf area observed with chicken manure in this study. Decomposed oil palm stems and river sand + chicken manure showed improved performance

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in later stages, confirming the value of organic-inorganic mixtures. Though coconut fibre improves aeration and drainage, it often needs nutrient supplementation to match organic-rich media. Reduced early growth in clay and sand + coconut fibre, with some later improvement, echoes studies by Albuquerque et al. (2008) and Andrezza da Silva et al. (2011), which stress that well-drained but inert media require added nutrients to foster leaf development. Hence, nutrient availability and physical traits of the substrate are both critical to early-stage leaf expansion.

Studies by Santos et al. (2021) showed that coconut-based media (cocopeat and husk powder) increased chlorophyll and seedling vigour in *Heliconia*, a result mirrored in this study where river sand + coconut fibre led to peak chlorophyll levels after 11 WAP. Silva et al. (2022) also found that pure coconut coir supported higher chlorophyll levels in spinach, indicating that coconut fibre favours sustained pigment development under regulated nutrients. These findings were consistent across both experiments, especially at peak growth around 19 WAP. However, some studies suggest coconut fibre's advantage is context-dependent. Makoni and Mwangi (2023) reported no significant difference in chlorophyll levels between coconut coir and loamy soil in pepper, and Jones et al. (2020) found peat-based media comparable to coir in petunias when fertigated. This suggests that while coconut fibre supports chlorophyll production, its success is influenced by the crop and nutrient management. The consistent performance of river sand + coconut fibre in this study implies it provides a balanced mix of aeration, moisture, and nutrients, essential for chlorophyll biosynthesis.

The linear relationships among ten key agronomic traits of *Heliconia psittacorum* across the two experimental runs revealed notable variations. In experiment 1, correlations were generally weak ($r < 0.3$), although moderate positive associations were observed between leaf number and leaf area ($r = 0.5655$), and stem girth with both stem length ($r = 0.5505$) and leaf number

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(r = 0.71). Negative correlations included sucker number with chlorophyll content (r = –0.3683) and fresh root biomass (r = –0.29), indicating potential competition for resources. These patterns align with findings by Kannan et al. (2019) and Safeena et al. (2023), who reported similar trade-offs between sucker proliferation and biomass accumulation, as well as moderate vegetative trait associations. In contrast, experiment 2 displayed stronger, more structured correlations. Dry and fresh root biomass (r = 0.84), dry and fresh shoot biomass (r = 0.80), and flower weight with shoot biomass and height (r = 0.50–0.41) were all positively linked. Negative relationships persisted, notably between leaf area and chlorophyll content (r = –0.45), and sucker number with various biomass traits, reinforcing the resource-allocation trade-off. These results are supported by Linares-Gabriel et al. (2024), who observed similar trends under improved environmental conditions. A seasonal comparison revealed clearer biological correlations in experiment 2, likely due to better growing conditions, echoing conclusions from agroforestry research (Scielo, 2023). Across both experiments, stem girth and stem length consistently correlated with biomass traits, validating their role as vigour indicators as supported by Safeena et al. (2023) and Linares-Gabriel et al. (2024). Conversely, sucker production remained negatively associated with key growth and chlorophyll parameters, highlighting a persistent trade-off in resource allocation. These findings underscore the importance of environmental consistency in trait analysis and the agronomic potential of managing sucker growth to optimize plant performance.

Some contradicting information were also observed in some of the vase life parameters studied. At 7 Days In Preservation (DIP), all treatments ranging from 0% to 20% sucrose showed no statistically significant differences in mean fresh weight (FW) loss (1.7–3.0 g), with identical superscript letters ('a') across treatments and minimal variation between the two experimental runs (0.4–1.3 g). Such findings align with Shokalu et al. (2019), who found negligible early-stage impact of sucrose on FW loss in *Heliconia* 'Golden Torch' flowers. Similarly,

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Carrera-Alvarado & Baltazar-Bernal (2021) reported stable weight loss in early vase life of *H. psittacorum*, suggesting that sucrose omission in early stages does not destabilize turgor balance, even under tropical temperature and relative humidity (R.H.) (26–29.5 °C; 76–83%).

By 14 DIP, trends remained similar until Exp. 2's 10% sucrose treatment exhibited significantly higher FW loss (7.0 g, 'c') compared to experiment 1 (4.8 g). This suggests osmotic imbalance or microbial degradation at moderate sucrose levels, a scenario reported in Chrysanthemum and Gerbera studies, where >10% sucrose elevated weight loss due to xylem clogging. The high coefficients of variation (up to 53–65% at 7 DIP and 40.6% at 14 DIP) reflect known variability in tropical flower experiments, likely tied to microbial fluctuations and minor environmental disturbances.

Examining vase solution uptake (VSU) revealed that at 7 DIP, the control group in Experiment 1 had the highest uptake (10.8 mL), significantly outperforming all sucrose treatments. In Experiment 2, uptake across treatments was statistically uniform (5.9–7.1 mL), but again the 0% group led. This unexpected trend resonates with Carrera-Alvarado & Baltazar-Bernal (2021), who also noted sucrose addition sometimes limited water intake, potentially due to osmotic pressures or microbial obstruction in stems.

By 14 DIP, uptake declined universally again, the control showed highest intake (5.3 and 3.1 mL) while sucrose treatments (1.4–2.2 mL) lagged. The lowest uptake variation (0.4 mL) occurred in the 15% group. This suggests sucrose at higher concentrations may impair vascular conductance, a phenomenon often intensified by microbial proliferation.

Regarding vase life, in experiment 1, the control group (0% sucrose) achieved the longest life (14.0 days), significantly surpassing sucrose treatments (10–20%: 12.1–13.3 days). In Experiment 2, vase life ranged narrowly (12.2–13.3 days) with no significant differences, and

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a slightly higher but non-significant 10% treatment. This aligns with Shokalu et al. (2019), where floral preservatives containing sucrose alone did not outperform water controls.

CO_2 respiration data revealed that 20% sucrose induced a high initial spike (~850 ppm) at Day 0, followed by a decline by Day 7, indicating the transient metabolic push often seen with high carbohydrate loads in roses and other species. In contrast, 10% sucrose showed a moderate increase by Day 7, illustrating a more sustained metabolic support, while distilled water remained lowest throughout supporting the idea that moderate sucrose fosters steady metabolic activity without overstimulation.

Visual quality, rated on a 1–4 scale, displayed some inconsistency. In experiment 1, 10% sucrose scored poorest (4), while control scored 2; in experiment 2, 10% improved (2), control declined (3), with both 15% and 20% treatments stable at 3. Variability in control and 10% groups (difference 1–2 points) suggests that moderate sucrose stabilizes aesthetics. This inconsistency agrees with the assertion that although sucrose can delay the senescence in many flowers, (Arrom and Munné-Bosch, 2012), its ability on flower quality can still be found to be inferior to several flower species.

Correlation analyses diverged between experiments. In experiment 1, strong negative correlations between FW loss at 14 DIP and vase life ($r = -0.74$), FW loss at 7 DIP ($r = -0.52$), and strong positive correlations of VSU at 7 and 14 DIP with vase life ($r = 0.65$ and 0.64) indicate a clear hydration longevity relationship. Conversely, experiment 2 produced weak/inverted correlations such as VSU positively correlating with FW loss ($r = 0.79$) suggesting experimental noise or microbial interference, echoing findings from Darras (2019)

Environmental records show a well-maintained climate (26–29.5 °C; 76–83% RH) with only a minor drop on Day 8, mirroring optimal conditions recommended for tropical Heliconia preservation.

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CHAPTER SIX

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

This study on *Heliconia psittacorum* highlights how growth media significantly affect sprouting, flowering, and vegetative development. Organic-rich substrates, particularly those amended with chicken manure and decomposed oil palm stems, consistently improved sprouting time, leaf area, and vegetative traits, aligning with prior findings on the benefits of organic matter in enhancing nutrient availability and moisture retention. Top soil with chicken manure yielded the best overall growth, while inconsistent results with coconut fibre and decomposed oil palm stem revealed the importance of nutrient stability and physical media properties. Period of cultivation influenced sprouting and flowering timelines, with experiment 2 generally showing stronger trait correlations and better performance. Substrate texture, nutrient composition, and environmental conditions were key to chlorophyll content, with coconut fibre supporting sustained pigment levels when paired with river sand. Negative correlations between sucker number and biomass across seasons confirmed resource allocation trade-offs. Overall, the findings emphasize selecting media based on organic quality and seasonal conditions to optimize *Heliconia* propagation and performance.

On the other hand, the vase life studies also revealed that sucrose alone neither reliably enhances Fresh Weight loss, water uptake, vase life, nor visual quality in cut *Heliconia psittacorum*. High concentrations may lead to osmotic stress and microbial blockage, while moderate levels offer metabolic support but inconsistent outcomes. Variability between experiments underscores the necessity of combining sucrose with antimicrobial agents (e.g., ClO_2, Hydraflor® 100, STS, or essential oils) to maintain xylem conductivity and extend longevity.

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6.2 Conclusions

Based on the results of the study, the following conclusions have been drawn:

- The growth media significantly influenced the agronomic traits of *Heliconia psittacorum*. Specifically, "Top soil + Chicken manure" consistently promoted the highest growth metrics regarding stem length, stem girth, leaf area, and number of leaves, suggesting that its balanced nutrient profile and effective moisture retention benefited *Heliconia* growth.
- " Top soil + Chicken manure" also contributed to faster sprouting times, proving its suitability for maximizing growth in *Heliconia psittacorum* as a result of its balanced nutrient profile.
- "Decomposed Oil Palm stems" also showed positive outcomes for early growth parameters like stem girth and number of leaves, particularly in the initial weeks after planting. This points to its effectiveness in supporting initial plant establishment.
- On the contrary, "River sand + Coconut Fibre" and "Clayey soil" substrates generally underperformed across growth parameters, likely due to their limited nutrient availability and poor water-holding capacity.
- In the vase life studies, distilled water proved most effective in minimizing fresh weight loss and maintaining vase solution uptake, resulting in longer vase life.
- On the other hand, higher sucrose concentrations (10 - 20%) were less effective, as they led to increased fresh weight loss and decreased water uptake, likely due to osmotic imbalances, and fluctuating humidity and CO_2 levels.

6.3 Recommendations

- For growers aiming to cultivate *Heliconia psittacorum* with optimal vegetative growth, " Top soil + Chicken manure" is recommended as the preferred potting medium due to its balanced moisture and nutrient-holding capacity, supporting robust and sustained growth.

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- It is advised that growers avoid clayey soil as much as possible, given its restrictive properties on root growth and overall plant vigour.
- Distilled water is recommended as a preservative solution for postharvest management of cut flowers. This medium promotes higher solution uptake and effectively maintains vase life without the complications posed by sucrose treatments.
- Further research is suggested to explore the interaction between vase solutions and environmental variables such as temperature and humidity to improve the commercial value and vase life of *H. psittacorum* in Ghana.
- Finally, future research could focus on optimizing the specific nutrient ratios in organic soil amendments, evaluating the combinations of organic and inorganic media amendments to improve water retention in low-performing substrates, and exploring alternative organic-based preservative solutions to enhance vase life further

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APPENDICES

Appendix 1: Analysis of variance (ANOVA) for Experiment one (Pot experiment)

Weeks_to_Sprouting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.1913	0.3971	1.56	
Treatments	5	4.2888	0.8578	3.36	0.031
Residual	15	3.8262	0.2551		
Total	**23**	**9.3063**			

Number of sprouts_at_Week_50

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	18.865	6.288	1.71	
Treatments	5	30.177	6.035	1.64	0.21
Residual	15	55.198	3.68		
Total	**23**	**104.24**			

Dry_root_biomass_at_Week_50

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	579	193	1.73	
Treatments	5	432.9	86.6	0.77	0.583
Residual	15	1675.9	111.7		
Total	**23**	**2687.8**			

Dry_shoot_biomass_at_Week_50

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	551.76	183.92	3.47	
Treatments	5	1393.57	278.71	5.25	0.006
Residual	15	796.17	53.08		
Total	**23**	**2741.51**			

Fresh_root_biomass_at_Week_50

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	6415	2138.3	2.72	
Treatments	5	3958.8	791.8	1.01	0.447
Residual	15	11788.2	785.9		
Total	**23**	**22162.1**			

Fresh_shoot_biomass_at_Week_50

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	4696.5	1565.5	2.93	
Treatments	5	8321.9	1664.4	3.12	0.04
Residual	15	8009.2	533.9		
Total	**23**	**21027.6**			

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Chlorophyll Content_ - Week 9

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	336.12	112.04	1.61	
Treatments	5	117.87	23.57	0.34	0.882
Residual	15	1045.24	69.68		
Total	**23**	**1499.24**			

Chlorophyll Content_ - Week 13

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	62.68	20.89	0.23	
Treatments	5	1700.48	340.1	3.78	0.02
Residual	15	1349.6	89.97		
Total	**23**	**3112.76**			

Chlorophyll Content_ - Week 15

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	29.64	9.88	0.21	
Treatments	5	1147.47	229.49	4.99	0.007
Residual	15	689.46	45.96		
Total	**23**	**1866.57**			

Chlorophyll Content_ - Week 17

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	132.35	44.12	1.73	
Treatments	5	162.65	32.53	1.27	0.325
Residual	15	382.87	25.52		
Total	**23**	**677.88**			

Chlorophyll Content_ - Week 19

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	128.82	42.94	0.89	
Treatments	5	1420.78	284.16	5.89	0.003
Residual	15	723.92	48.26		
Total	**23**	**2273.52**			

Chlorophyll Content_ - Week 21

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	259.12	86.37	2.35	
Treatments	5	1379.75	275.95	7.51	0.001
Residual	15	551.48	36.77		
Total	**23**	**2190.36**			

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Leaf Area_ - Week 9

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	2258.4	752.8	2.26	
Treatments	5	13105.6	2621.1	7.86	<.001
Residual	15	5002.5	333.5		
Total	**23**	**20366.6**			

Leaf Area_ - Week 11

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	11640	3880	3.13	
Treatments	5	17954	3591	2.89	0.05
Residual	15	18606	1240		
Total	**23**	**48200**			

Leaf Area_ - Week 13

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	12583	4194	2.63	
Treatments	5	26983	5397	3.38	0.03
Residual	15	23967	1598		
Total	**23**	**63533**			

Leaf Area_ - Week 15

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	30627	10209	4.25	
Treatments	5	6926	1385	0.58	0.717
Residual	15	36038	2403		
Total	**23**	**73590**			

Leaf Area_ - Week 17

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	23587	7862	3.7	
Treatments	5	7473	1495	0.7	0.63
Residual	15	31876	2125		
Total	**23**	**62936**			

Leaf Area_ - Week 19

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	4518	1506	0.84	
Treatments	5	16271	3254	1.82	0.17
Residual	15	26885	1792		
Total	**23**	**47675**			

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Leaf Area_ - Week 21

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	4480	1493	1.06	
Treatments	5	1669	334	0.24	0.94
Residual	15	21175	1412		
Total	**23**	**27324**			

Number of Leaves per plant_ - Week 9

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.2083	0.4028	2.79	
Treatments	5	6.5833	1.3167	9.12	<.001
Residual	15	2.1667	0.1444		
Total	**23**	**9.9583**			

Number of Leaves per plant_ - Week 11

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.7812	0.2604	0.62	
Treatments	5	7.6771	1.5354	3.67	0.023
Residual	15	6.2812	0.4187		
Total	**23**	**14.7396**			

Number of Leaves per plant_ - Week 13

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.0417	0.3472	0.79	
Treatments	5	4.8333	0.9667	2.2	0.108
Residual	15	6.5833	0.4389		
Total	**23**	**12.4583**			

Number of Leaves per plant_ - Week 15

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.2083	0.4028	2.64	
Treatments	5	3.125	0.625	4.09	0.015
Residual	15	2.2917	0.1528		
Total	**23**	**6.625**			

Number of Leaves per plant_ - Week 17

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.6146	0.2049	0.45	
Treatments	5	2.5521	0.5104	1.12	0.39
Residual	15	6.8229	0.4549		
Total	**23**	**9.9896**			

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Number of Leaves per plant - Week 19

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	3	1	1.09	
Treatments	5	3.5833	0.7167	0.78	0.578
Residual	15	13.75	0.9167		
Total	**23**	**20.3333**			

Stem Girth_ - Week 9

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	28.538	9.513	1.57	
Treatments	5	273.34	54.668	9.02	<.001
Residual	15	90.901	6.06		
Total	**23**	**392.779**			

Stem Girth_ - Week 11

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	2.083	0.694	0.08	
Treatments	5	300.658	60.132	6.87	0.002
Residual	15	131.272	8.751		
Total	**23**	**434.013**			

Stem Girth_ - Week 13

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	247.28	82.43	4.19	
Treatments	5	214.68	42.94	2.18	0.111
Residual	15	295.03	19.67		
Total	23	756.99			

Stem Girth_ - Week 15

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Block stratum	3	201.68	67.23	2.85		
Treatments	5	197.97	39.59	1.68		0.2
Residual	15	353.75	23.58			
Total	**23**	**753.4**				

Stem Girth_ - Week 17

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	119.43	39.81	1.57	
Treatments	5	152.12	30.42	1.2	0.356
Residual	15	380.44	25.36		
Total	**23**	**651.99**			

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Stem Girth _ - Week 19

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	133.71	44.57	1.41	
Treatments	5	246.4	49.28	1.56	0.232
Residual	15	475.31	31.69		
Total	**23**	**855.42**			

Stem Girth_ - Week 21

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	217.5	72.5	1.51	
Treatments	5	154.75	30.95	0.64	0.67
Residual	15	720.97	48.06		
Total	**23**	**1093.22**			

Stem length_Week 9

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	20.115	6.705	1.74	
Treatments	5	150.427	30.085	7.82	<.001
Residual	15	57.698	3.847		
Total	23	228.24			

Stem length_Week 11

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	35.552	11.851	2.28	
Treatments	5	221.74	44.348	8.53	<.001
Residual	15	77.948	5.197		
Total	**23**	**335.24**			

Stem length_Week 13

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	37.154	12.385	2.65	
Treatments	5	111.763	22.353	4.78	0.008
Residual	15	70.206	4.68		
Total	**23**	**219.122**			

Stem length_Week 15

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	24.57	8.19	1.6	
Treatments	5	64.826	12.965	2.53	0.075
Residual	15	76.727	5.115		
Total	**23**	**166.122**			

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Stem length_Week 17

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	23.458	7.819	1.79	
Treatments	5	69.75	13.95	3.2	0.037
Residual	15	65.417	4.361		
Total	**23**	**158.625**			

Stem length_Week 19

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	69.333	23.111	4.15	
Treatments	5	90.844	18.169	3.27	0.034
Residual	15	83.448	5.563		
Total	**23**	**243.625**			

Stem length_Week 21

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	30.281	10.094	1.63	
Treatments	5	58.896	11.779	1.9	0.154
Residual	15	92.938	6.196		
Total	**23**	**182.115**			

Appendix 2: Analysis of variance (ANOVA) for Experiment two (Pot experiment)

Days_to_flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	350.8	116.9	0.56	
Treatments	5	2443.9	488.8	2.35	0.091
Residual	15	3113.7	207.6		
Total	**23**	**5908.4**			

Weeks_to_Sprouting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.6233	0.2078	0.57	
Treatments	5	1.995	0.399	1.1	0.399
Residual	15	5.4217	0.3614		
Total	**23**	**8.04**			

No_of_sprouts_at_Week_50

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	13.994	4.665	3.47	
Treatments	5	19.006	3.801	2.83	0.054
Residual	15	20.138	1.343		
Total	**23**	**53.138**			

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Dry_root_biomass_at_Week_50

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	36.99	12.33	0.8	
Treatments	5	152.46	30.49	1.98	0.14
Residual	15	231.12	15.41		
Total	**23**	**420.57**			

Dry_shoot_biomass_at_Week_50

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	248.25	82.75	2.33	
Treatments	5	171.66	34.33	0.96	0.47
Residual	15	533.67	35.58		
Total	23	953.59			

Fresh_root_biomass_at_Week_50

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	438.1	146	0.9	
Treatments	5	261.7	52.3	0.32	0.891
Residual	15	2428.1	161.9		
Total	**23**	**3127.9**			

Fresh_shoot_biomass_at_Week_50

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	1293.4	431.1	0.71	
Treatments	5	2536.6	507.3	0.84	0.543
Residual	15	9082.8	605.5		
Total	23	12912.7			

Fresh_shoot_biomass_at_Week_50

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	1293.4	431.1	0.71	
Treatments	5	2536.6	507.3	0.84	0.543
Residual	15	9082.8	605.5		
Total	23	12912.7			

Chlorophyll Content_Week 9

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	84.31	28.1	0.47	
Treatments	5	677.84	135.57	2.28	0.099
Residual	15	890.18	59.35		
Total	**23**	**1652.34**			

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Chlorophyll Content_Week 11

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	219.36	73.12	1.48	
Treatments	5	857.63	171.53	3.47	0.028
Residual	15	740.67	49.38		
Total	**23**	**1817.65**			

Chlorophyll Content_Week 13

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	231.6	77.2	1.71	
Treatments	5	351.54	70.31	1.56	0.231
Residual	15	676.85	45.12		
Total	**23**	**1260**			

Chlorophyll Content_Week 15

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	40.3	13.43	0.34	
Treatments	5	564.97	112.99	2.85	0.053
Residual	15	594.29	39.62		
Total	**23**	**1199.56**			

Chlorophyll Content_Week 17

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	89.64	29.88	0.72	
Treatments	5	187.01	37.4	0.91	0.502
Residual	15	618.87	41.26		
Total	**23**	**895.52**			

Chlorophyll Content_Week 19

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	143.37	47.79	2.67	
Treatments	5	969.86	193.97	10.86	<.001
Residual	15	268.02	17.87		
Total	**23**	**1381.25**			

Chlorophyll Content_Week 21

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	73.69	24.56	0.62	
Treatments	5	572.23	114.45	2.88	0.051
Residual	15	597.04	39.8		
Total	**23**	**1242.97**			

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Leaf Area_Week 9

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	3077	1026	0.3	
Treatments	5	10896	2179	0.63	0.68
Residual	15	51869	3458		
Total	**23**	**65842**			

Leaf Area_Week 11

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	179.9	60	0.08	
Treatments	5	11759.6	2351.9	3.19	0.037
Residual	15	11067	737.8		
Total	**23**	**23006.5**			

Leaf Area_Week 13

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1929	643	0.27	
Treatments	5	21790	4358	1.8	0.173
Residual	15	36279	2419		
Total	**23**	**59998**			

Leaf Area_Week 15

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	7108	2369	1.53	
Treatments	5	24442	4888	3.16	0.038
Residual	15	23242	1549		
Total	**23**	**54792**			

Leaf Area_Week 17

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	4377	1459	0.79	
Treatments	5	22859	4572	2.46	0.081
Residual	15	27865	1858		
Total	**23**	**55101**			

Leaf Area_Week 19

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	13945	4648	2.95	
Treatments	5	34629	6926	4.39	0.012
Residual	15	23650	1577		
Total	**23**	**72224**			

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Leaf Area_Week 21

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	4150	1383	0.63	
Treatments	5	6892	1378	0.62	0.684
Residual	15	33159	2211		
Total	**23**	**44200**			

Number of Leaves_Week 9

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	0.7083	0.2361	1.85	
Treatments	5	0.8333	0.1667	1.3	0.314
Residual	15	1.9167	0.1278		
Total	**23**	**3.4583**			

Number of Leaves_Week 11

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	0.9167	0.3056	1.55	
Treatments	5	1.9583	0.3917	1.99	0.139
Residual	15	2.9583	0.1972		
Total	**23**	**5.8333**			

Number of Leaves_Week 13

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	1.2083	0.4028	0.87	
Treatments	5	1.8333	0.3667	0.8	0.57
Residual	15	6.9167	0.4611		
Total	**23**	**9.9583**			

Number of Leaves_Week 15

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	1.0833	0.3611	1.34	
Treatments	5	0.875	0.175	0.65	0.666
Residual	15	4.0417	0.2694		
Total	**23**	**6**			

Number of Leaves_Week 17

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	1.7812	0.5938	0.81	
Treatments	5	0.4271	0.0854	0.12	0.987
Residual	15	11.0312	0.7354		
Total	23	13.2396			

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Number of Leaves_Week 19

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.2812	0.0938	0.24	
Treatments	5	1.4271	0.2854	0.74	0.605
Residual	15	5.7812	0.3854		
Total	**23**	**7.4896**			

Number of Leaves_Week 21

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.0833	0.3611	1.65	
Treatments	5	2.9583	0.5917	2.7	0.062
Residual	15	3.2917	0.2194		
Total	**23**	**7.3333**			

Stem Girth_Week 9

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	9.111	3.037	1.25	
Treatments	5	41.797	8.359	3.44	0.029
Residual	15	36.451	2.43		
Total	**23**	**87.36**			

Stem Girth_Week 11

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	84.071	28.024	5.76	
Treatments	5	35.422	7.084	1.46	0.262
Residual	15	72.996	4.866		
Total	**23**	**192.49**			

Stem Girth_Week 13

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	58.86	19.62	1.4	
Treatments	5	74.24	14.85	1.06	0.421
Residual	15	210.58	14.04		
Total	**23**	**343.67**			

Stem Girth_Week 15

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	34.09	11.36	0.68	
Treatments	5	118.59	23.72	1.43	0.27
Residual	15	248.85	16.59		
Total	**23**	**401.53**			

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Stem Girth_Week 17

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	85.26	28.42	2.04	
Treatments	5	130.97	26.19	1.88	0.157
Residual	15	208.79	13.92		
Total	**23**	**425.03**			

Stem Girth_Week 19

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	188.34	62.78	3.67	
Treatments	5	120.73	24.15	1.41	0.276
Residual	15	256.5	17.1		
Total	**23**	**565.57**			

Stem Girth_Week 21

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	227.29	75.76	3.7	
Treatments	5	85.64	17.13	0.84	0.544
Residual	15	307.1	20.47		
Total	**23**	**620.04**			

Stem Length_Week 9

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	6.219	2.073	0.71	
Treatments	5	44	8.8	3.03	0.044
Residual	15	43.562	2.904		
Total	**23**	**93.781**			

Stem Length_Week 11

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	8.708	2.903	0.51	
Treatments	5	79.24	15.848	2.76	0.058
Residual	15	86.135	5.742		
Total	**23**	**174.083**			

Stem Length_Week 13

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	42.167	14.056	1.58	
Treatments	5	87.333	17.467	1.96	0.143
Residual	15	133.333	8.889		
Total	**23**	**262.833**			

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Stem Length_Week 15

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	56.9	18.97	1.66	
Treatments	5	73.68	14.74	1.29	0.32
Residual	15	171.51	11.43		
Total	**23**	**302.08**			

Stem Length_Week 17

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	54.77	18.26	0.7	
Treatments	5	168.72	33.74	1.3	0.316
Residual	15	390.01	26		
Total	**23**	**613.5**			

Stem Length_Week 19

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	61.59	20.53	0.81	
Treatments	5	155.24	31.05	1.23	0.344
Residual	15	378.91	25.26		
Total	**23**	**595.74**			

Stem Length_Week 21

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	39.63	13.21	0.23	
Treatments	5	145.49	29.1	0.51	0.763
Residual	15	851.17	56.74		
Total	**23**	**1036.29**			

Appendix 3: Analysis of variance (ANOVA) for Vase life studies-Experiment 1

(CO_2_Day_0)_-_2_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	18574	6191	1.96	0.198
Residual	8	25218	3152		
Total	**11**	**43792**			

(CO_2_Day_0)_-_4_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	29578	9859	1.9	0.208
Residual	8	41462	5183		
Total	**11**	**71040**			

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(CO_2_Day_0) - _6_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	27486	9162	1.66	0.252
Residual	8	44236	5530		
Total	**11**	**71722**			

(CO_2_Day_0) - _8_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	29141	9714	1.45	0.299
Residual	8	53608	6701		
Total	**11**	**82749**			

(CO_2_Day_0) - 10_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	58903	19634	3.08	0.09
Residual	8	50942	6368		
Total	**11**	**109845**			

(CO_2_Day_7) - _2_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	49651	16550	4.01	0.052
Residual	8	33033	4129		
Total	**11**	**82684**			

(CO_2_Day_7) - _4_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	29286	9762	6.11	0.018
Residual	8	12782	1598		
Total	**11**	**42068**			

(CO_2_Day_7) - _8_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	21896.9	7299	9.36	0.005
Residual	8	6240	780		
Total	**11**	**28136.9**			

(RH_%_Day_0)_10_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	19.67	6.56	0.43	0.737
Residual	8	122	15.25		
Total	**11**	**141.67**			

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(RH_%_Day_0)__2_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	107.67	35.89	0.88	0.49
Residual	8	325.33	40.67		
Total	**11**	**433**			

(RH_%_Day_0)_4_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	49.67	16.56	0.8	0.529
Residual	8	166	20.75		
Total	**11**	**215.67**			

(RH_%_Day_0)_6_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	46.92	15.64	0.88	0.491
Residual	8	142	17.75		
Total	**11**	**188.92**			

(RH_%_Day_0)_8_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	26.25	8.75	0.49	0.697
Residual	8	142	17.75		
Total	**11**	**168.25**			

(RH_%_Day_7)_10_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	41.6667	13.8889	18.52	<.001
Residual	8	6	0.75		
Total	**11**	**47.6667**			

(RH_%_Day_7)__2_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	24.667	8.222	2.35	0.149
Residual	8	28	3.5		
Total	**11**	**52.667**			

(RH_%_Day_7)__4_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	519	173	0.91	0.477
Residual	8	1518.7	189.8		
Total	11	2037.7			

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(RH_%_Day_7)__6_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	30.333	10.111	8.67	0.007
Residual	8	9.333	1.167		
Total	**11**	**39.667**			

(RH_%_Day_7)__8_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	35.6667	11.8889	12.97	0.002
Residual	8	7.3333	0.9167		
Total	**11**	**43**			

(Temp._Day_0)_10_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	1.2	0.4	0.74	0.556
Residual	8	4.3067	0.5383		
Total	**11**	**5.5067**			

(Temp._Day_0)__2_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	7.609	2.536	0.86	0.502
Residual	8	23.713	2.964		
Total	11	31.323			

(Temp._Day_0)_4_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	3.429	1.143	0.88	0.489
Residual	8	10.34	1.293		
Total	11	13.769			

(Temp._Day_0)_6_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	2.5667	0.8556	0.88	0.492
Residual	8	7.8	0.975		
Total	**11**	**10.3667**			

(Temp._Day_0)_8_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	1.5367	0.5122	0.72	0.566
Residual	8	5.66	0.7075		
Total	**11**	**7.1967**			

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(Temp._Day_7)_10_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	1.949	0.65	0.33	0.805
Residual	8	15.84	1.98		
Total	11	17.789			

(Temp._Day_7)_2_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	3.0625	1.0208	5.21	0.028
Residual	8	1.5667	0.1958		
Total	**11**	**4.6292**			

(Temp._Day_7)_4_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	574.7	191.6	1	0.441
Residual	8	1530.5	191.3		
Total	**11**	**2105.2**			

(Temp._Day_7)_6_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	1.6225	0.54083	7.13	0.012
Residual	8	0.60667	0.07583		
Total	**11**	**2.22917**			

(Temp._Day_7)_8_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	35.6667	11.8889	12.97	0.002
Residual	8	7.3333	0.9167		
Total	**11**	**43**			

(Temp._Day_7)_8_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	1.17667	0.39222	7.47	0.01
Residual	8	0.42	0.0525		
Total	**11**	**1.59667**			

Vase_solution_uptake_mls_DAY_14

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	22.3241	7.4414	7.88	0.009
Residual	8	7.5556	0.9444		
Total	**11**	**29.8796**			

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Vase_solution_uptake_mls_DAY_7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	83.065	27.688	17.29	<.001
Residual	8	12.815	1.602		
Total	**11**	**95.88**			

Vase_life_days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	5.81481	1.93827	104.67	<.001
Residual	8	0.14815	0.01852		
Total	**11**	**5.96296**			

Visual rating

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	3.33333	1.11111	40.00	<.001
Residual	8	0.22222	0.02778		
Total	**11**	**3.55556**			

Appendix 4: Analysis of variance (ANOVA) for Vase life studies-Experiment 2

(CO_2_Day_0)_10_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	40940	13647	3.63	0.064
Residual	8	30089	3761		
Total	**11**	**71028**			

(CO_2_Day_0)_2_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	16839	5613	2.69	0.117
Residual	8	16706	2088		
Total	**11**	**33545**			

(CO_2_Day_0)_4_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	16465	5488	2.64	0.121
Residual	8	16662	2083		
Total	**11**	**33127**			

(CO_2_Day_0)_6_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	14471	4824	1.77	0.23
Residual	8	21761	2720		
Total	11	36233			

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(CO_2_Day_0)_8_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	15535	5178	1.31	0.336
Residual	8	31558	3945		
Total	**11**	**47093**			

(CO_2_Day_7)_10_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	20044.9	6681.6	7.27	0.011
Residual	8	7353.3	919.2		
Total	**11**	**27398.2**			

(CO_2_Day_0)_2_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	59171	19724	4.56	0.038
Residual	8	34633	4329		
Total	**11**	**93804**			

(CO_2_Day_0)__4_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	34879	11626	6.91	0.013
Residual	8	13465	1683		
Total	**11**	**48345**			

(CO_2_Day_0)__6_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	22014	7338	6.75	0.014
Residual	8	8703	1088		
Total	**11**	**30718**			

(CO_2_Day_0)__8_mins

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	21896.9	7299	9.36	0.005
Residual	8	6240	780		
Total	**11**	**28136.9**			

Fresh_weight_loss_g_DAY_7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	3	2.587	0.862	0.47	0.713
Residual	8	14.74	1.843		
Total	**11**	**17.327**			

Fresh_weight_loss_g_DAY_14

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

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Treatments	3	17.096	5.699	1.51	0.284
Residual	8	30.165	3.771		
Total	**11**	**47.261**			

(CO_2_Day_0)_10_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	19.67	6.56	0.43	0.737
Residual	8	122	15.25		
Total	**11**	**141.67**			

RH_%_Day_0_2_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	107.67	35.89	0.88	0.49
Residual	8	325.33	40.67		
Total	**11**	**433**			

RH_%_Day_0_4_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	49.67	16.56	0.8	0.529
Residual	8	166	20.75		
Total	**11**	**215.67**			

RH_%_Day_0_6_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	46.92	15.64	0.88	0.491
Residual	8	142	17.75		
Total	**11**	**188.92**			

RH_%_Day_0_8_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	26.25	8.75	0.49	0.697
Residual	8	142	17.75		
Total	**11**	**168.25**			

RH_%_Day_7_10_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	41.6667	13.8889	18.52	<.001
Residual	8	6	0.75		
Total	**11**	**47.6667**			

RH_%_Day_7_2_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**

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Treatments	3	24.667	8.222	2.35	0.149
Residual	8	28	3.5		
Total	**11**	**52.667**			

RH_%_Day_7_4_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	27.333	9.111	3.9	0.055
Residual	8	18.667	2.333		
Total	**11**	**46**			

RH_%_Day_7_6_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	30.333	10.111	8.67	0.007
Residual	8	9.333	1.167		
Total	**11**	**39.667**			

RH_%_Day_7_8_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	35.6667	11.8889	12.97	0.002
Residual	8	7.3333	0.9167		
Total	**11**	**43**			

(Temp._Day_0)_10_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	1.2	0.4	0.74	0.556
Residual	8	4.3067	0.5383		
Total	**11**	**5.5067**			

(Temp._Day_0)__2_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	7.609	2.536	0.86	0.502
Residual	8	23.713	2.964		
Total	**11**	**31.323**			

(Temp._Day_0)_4_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	3.429	1.143	0.88	0.489
Residual	8	10.34	1.293		
Total	**11**	**13.769**			

(Temp._Day_0)__6_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**

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Treatments	3	2.5667	0.8556	0.88	0.492
Residual	8	7.8	0.975		
Total	**11**	**10.3667**			

(Temp._Day_0)__8_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	1.5367	0.5122	0.72	0.566
Residual	8	5.66	0.7075		
Total	**11**	**7.1967**			

(Temp._Day_7)_10_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	1.949	0.65	0.33	0.805
Residual	8	15.84	1.98		
Total	**11**	**17.789**			

(Temp._Day_7)_2_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	3.0625	1.0208	5.21	0.028
Residual	8	1.5667	0.1958		
Total	**11**	**4.6292**			

(Temp._Day_7)_4_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	574.7	191.6	1	0.441
Residual	8	1530.5	191.3		
Total	**11**	**2105.2**			

(Temp._Day_7)_6_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	1.6225	0.54083	7.13	0.012
Residual	8	0.60667	0.07583		
Total	**11**	**2.22917**			

(Temp._Day_7)_8_mins

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	1.17667	0.39222	7.47	0.01
Residual	8	0.42	0.0525		
Total	**11**	**1.59667**			

Vase_solution_uptake_mls_DAY_7

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**

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Treatments	3	2.407	0.802	0.21	0.885
Residual	8	30.148	3.769		
Total	**11**	**32.556**			

Vase_life_days

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	1.963	0.654	0.38	0.77
Residual	8	13.778	1.722		
Total	**11**	**15.741**			

Vase_solution_uptake_mls_DAY_14

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	5.583	1.861	1.62	0.26
Residual	8	9.185	1.148		
Total	**11**	**14.769**			

Visual rating

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Treatments	3	3.2130	1.0710	2.75	0.112
Residual	8	3.1111	0.3889		
Total	**11**	**6.3241**			

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