Selenicereus undatus Haw.

Dragon Fruit

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1.0 Introduction

Selenicereus undatus, commonly known as dragon fruit, is a species whose success relies on the alignment of multiple ecological and environmental factors that work together rather than in isolation. Its growth reveals the intimate connections between soil chemistry, geological formation, climate patterns, and nutrient availability, which is why a single perspective is never enough to understand how this plant develops and sustains itself. The monograph begins by situating the species within its ecological context, recognizing that its adaptation to tropical and subtropical environments reflects centuries of evolutionary pressures that shaped its physiology, rooting behavior, and metabolic structure. From there, each section examines a different dimension of its habitat. The soils and underlying geology determine the physical and chemical support systems that allow the plant to anchor, absorb water, and access essential minerals. Climate factors influence its photosynthetic rhythm, temperature tolerance, and reproductive cycles. Nutrient requirements reveal the biochemical demands that maintain healthy growth and fruit production. By combining scientific research, environmental analysis, and cultivated observations, this monograph seeks to provide a complete and coherent understanding of *Selenicereus undatus.* The goal is not only to describe how the species interacts with its environment, but also to clarify why these interactions matter for its long-term health, sustainability, and agricultural value.

This species was selected due to its growing global importance as both an agricultural crop and a model for understanding plant adaptation under varying environmental conditions. Its ability to thrive in challenging climates, combined with its economic relevance in international markets, makes it a valuable case study for examining how biological traits and environmental factors interact to support successful cultivation. Following this perspective, **Chapter 2** establishes the foundational context of the species, including its taxonomy, origin, and distribution, while also introducing the environmental conditions that define its natural range. It expands on this by analyzing the external factors that influence growth, such as soil properties, geological characteristics, climate patterns, and nutrient availability. **Chapter 3** focuses on the internal biological processes of the plant, including its life cycle, reproductive mechanisms, and physiological adaptations that allow it to function efficiently within its environment. **Chapter 4** connects this scientific understanding to practical applications by examining propagation methods, cultivation practices, and management strategies used in agricultural systems. **Chapter 5** broadens the discussion by exploring the economic importance of *Selenicereus undatus*, including its production patterns, commercialization, and growing role in national and international markets. Finally, **Chapter 6** includes a final analysis of all the information that will be covered in this monograph. Together, these chapters provide a structured and comprehensive examination that explains not only how *Selenicereus undatus* grows, but also why its interaction with the environment is essential for its continued productivity, commercial relevance, and sustainability.

2.0 Agroecology

2.1 Taxonomic Classification of *Selenicereus undatus*

2.1.1 Botanical Authority

The correct way to refer to the dragon fruit scientifically is *Selenicereus undatus* (Haw.) D.R. Hunt. It has a rich taxonomic history, as seen in **Table 1**, which reflects the ongoing evolution of botanical classification. It was first described in 1830 by the English botanist Adrian Hardy Haworth, who placed it in the genus *Cereus* as *Cereus undatus* (Haworth, 1830). Almost a century later, American Botanists Nathaniel Lord Britton and Joseph Nelson Rose transferred the species to the genus *Hylocereus*, creating the name *Hylocereus undatus* in their influential monograph *The Cactaceae* (1918-1923) (Britton & Rose, 2015). This remained the standard for most of the 20th century and is still reflected in databases such as the USDA Plant Database. However, modern phylogenetic work, particularly the studies and revisions by David R. Hunt, demonstrated that *Hylocereus* is not a validly separate genus but is instead nested within *Selenicereus*. In 2017, Hunt formally reassigned the plant to *Selenicereus undatus*, which is now widely accepted as the correct classification (Hunt, 2017). The recognition of Haworth as the original authority and Hunt as the revising authority highlights the historical roots and the modern refinement of plant taxonomy, as seen when naming the plant with the botanical authority.

Table 1

Taxonomic Hierarchy of Selenicereus undatus

TAXONOMIC RANK	TAXON NAME (AUTHORITY)
Kingdom	Plantae
Subkingdom	Tracheophyta (vascular plants)
Superdivision	Spermatophyta (Seed plants)
Class	Magnoliopsida (dicotyledons)
Order	Caryophyllales
Family	Cactaceae
Genus	*Selenicereus*
Species	*Selenicereus undatus*

Note. Table amended from USDA Plant Database (USDA, 2025). It represents the taxonomic hierarchy of *Selenicereus undatus*. *Selenicereus undatus* is situated in the Kingdom Plantae that includes all plants, these being multicellular, photosynthetic organisms with cellulose-based cell walls (Oxford Dictionary of Plant Sciences, 1992). Tracheophyta refers to vascular plants that have a xylem and phloem. Magnoliopsida *(dicotyledons)* includes species with two cotyledons and net-like leaf Venetian. *Caryophyllenes* are identified by features of betalain pigments and succulent adaptations (Thorne & Reveal, 2007). Cactaceae is the cactus family, known for juicy stems and specialized areoles. *Selenicereus* is a genus of climbing, night-blooming cacti. *Selenicereus undatus* is the species name, commonly called dragon fruit (USDA, 2025).

2.1.2 Kingdom to Division

At the broadest level, dragon fruit belongs to the kingdom Plantae, which includes all multicellular, photosynthetic organisms with cellulose-based cell walls. Plants in this kingdom are the foundation for terrestrial ecosystems, contributing oxygen, food and primary productivity (Simpson, 2019). With nearly 390,000 vascular plant species recognized, Plantae is a vast and diverse group (Christenhusz & Byng, 2016). Within this kingdom, dragon fruit is classified in the subkingdom Tracheophyta, the vascular plants. These plants, numbering around 300,000 species, are defined by their vascular tissues, the xylem and phloem. These allow efficient transport of water, nutrients, and sugars throughout the body. This evolutionary adaptation permitted plants to grow, occupy new niches and spread widely across ecosystems (Evert & Eichhorn, 2013).

Further narrowing, the plant belongs to the superdivision Spermatophyta, the seed plants, with roughly 260,000 species worldwide (Judd, Campbell, Kellogg, Stevens, & Donoghue, 2010). Seed production represents a crucial evolutionary innovation compared to spore-bearing plants. Seeds enclose and protect the embryo, provide stored nutrients, and often have structures for dispersal, giving seed plants clear ecological advantages. Within Spermatophyta, dragon Fruit is placed in the division *Magnoliophyta* (flowering plants). This group, with approximately 250,000 species, is characterized by producing flowers as reproductive organs and enclosing seeds within fruits (Simpson, 2019). For dragon fruit, this classification is apparent: the large flowers open at night and their pollination lead to the development of fleshy, edible fruits containing numerous small black seeds.

2.1.3 Class to Order

Within *Magnoliophyta*, the USDA lists dragon fruit in the Class Magnoliopsida *(dicotyledons)*. Dicots are defined by traits such as two embryonic seed leaves *(cotyledons)*, reticulate leaf venation, and floral organs typically arranged in multiples of four or five, as seen in **Figure 1**. With about 200,000 species, this class represents a major portion of global angiosperm diversity (USDA, 2025) (Simpson, 2019). The next taxonomic step is the Order Caryophyllales are distinctive for their biochemistry and morphology: they often contain betalain pigments, rather than the *anthocyanins* found in most other flowering plants. These pigments produce bright red, yellow, and purple coloration, as seen in dragon's fruit flesh (Brockington et al., 2011). Caryophyllales also includes many species with succulent growth forms, a reflection of adaptation to dry or epiphytic environments.

Figure 1

Example of a Leafy Caryophyllaceae Species (Silene latifolia), Showing Thin Leaves With Netted Venation.

Note. Photo extracted from Native Plant Trust (Lovit, 2025). It highlights the contrast between leafy *Caryophyllaceae* and succulent members of the order Caryophyllales, such as the Cactaceae.

2.1.4 Family to Species

The family Cactaceae, to which dragon fruit belongs, is one of the most distinctive in the plant kingdom, containing around 1,900 species across 130 genera (Anderson, 2001). As shown in **Figure 2**, members of this family are recognized by their photosynthetic stems, the near absence or reduction of leaves, and the presence of specialized areoles. Areoles are cushion-like structures unique to cacti, from which spines, flowers, or new branches emerge. These traits represent specialized adaptations to conserve water and reduce transpiration, explaining the ecological success of cacti across deserts and tropical forests. Within Cactaceae, dragon fruit belongs to the Genus *Selenicereus*, a group of about 30 species. These are climbing cacti, normally using aerial roots to anchor themselves to trees or rocks. As seen in **Figure 3**, Their enormous, fragrant, flowers open only at night, a strategy adapted for pollination by nocturnal animals such as bats and moths (Hunt, 2017).

Figure 2

Close-Up of Cactus Stem (Cactaceae) Showing Areoles.

Note. Image amended from BiologyOne Digital Library (Mauseth, 2017). The areoles function as specialized structures from which spines and flowers emerge. These succulent adaptations illustrate the divergence of the cactus lineage within Caryophyllales (National Park Service, 2025).

Figure 3

Nocturnal Flower of Selenicereus undatus.

Note. Picture used from Georgette Kilgore (Kilgore, 2024). The flowers open at night and allow pollinators to come and ensure fruit set and to protect their sensitive floral structure from the daytime heat (Scott, 2024).

At the most specific level, the Species *Selenicereus undatus* is distinguished by its triangular stems with wavy ribs, the feature referenced in its epithet undatus, meaning “wavy”. Its fruits, with the white pulp speckled by small black seeds, as seen in **Figure 4,** are the most widely cultivated of all dragon fruit species, making this plant important not only botanically but also economically and culturally (Siddiq, 2012). It is grown across tropical and subtropical regions around the world, valued for its nutritional qualities, ornamental flowers, and adaptability to different environments.

Figure 4

Cross-Section of the Fruit of Selenicereus undatus

Note. Image acquired from New Oxford Book of Food Plants (Vaughan, 2009). It highlights its pink rind, white pulp, and numerous small black seeds (Blancke, 2016).

Understanding the taxonomy of *Selenicereus undatus* provides a foundation for exploring how the species fits within the broader evolutionary history of plants. Taxonomic classification not only identifies relationships among living species and organisms, but also reveals the traits that link them to their ancestral lineages. Once these hierarchies have been established, examining the fossil evidence, origin, and distribution of the species helps explain how those classifications developed through time and space. For *Selenicereus undatus*, this approach is of especial importance because its family, the *Cactaceae*, has a limited fossil record and a history shaped by environmental adaptation rather than abundant paleontological evidence. By combining molecular, ecological, and geographic data, it becomes possible to trace how this tropical cactus evolved, where it first appeared, and how human activity has expanded its presence across the globe.

2.2 Fossil record of *Selenicereus undatus*

The fossil record of dragon fruit is virtually nonexistent, which is also true for most species in the cactus family of *Cactaceae.* Unlike trees and other vascular plants that produce woody tissues capable of fossilization, cacti have soft, water-filled stems that decompose rapidly under normal environment conditions. As a result, almost no fossilized remains of cacti have been preserved in sedimentary rock (Guerrero, Majure, Cornejo-Romero, & Hernández-Hernández, 2019). Researchers studying the family's history emphasize that its evolutionary timeline must therefore be reconstructed using indirect evidence and molecular data rather than traditional fossils. Despite this, through genetic analysis, certain paleobotanical findings, particularly from preserved pack rat (Neotoma) middens, which are seen in **Figure 5**, are made of vegetation and debris, and they have provided valuable information about the ancient presence of cacti in arid landscapes in dry cave systems of the American Southwest, including spines and seeds (Thompson, Hernández-Hernández, Keeling, Vásquez, & Priest, 2024).

Radiocarbon analysis indicates that these remains date to roughly 20-30 thousand years ago, confirming that *Cactaceae* species were already well adapted to desert ecosystems in the modern-day world (Thompson et al., 2024). Because physical fossils are rare, molecular phylogenetics has become the main tool for tracing cactus evolution. Comparative DNA studies revealed that *Cactaceae* diverged from its closest relatives about 30-35 million years ago and underwent major diversification during the Miocene epoch between 10 and 5 million years ago

(Arakaki et al., 2011). These evolutionary changes coincided with climatic shifts that expanded arid and semi-arid habitats across the Americas, promoting the development of adaptations such as stem water storage, protective spines and Crassulacean Acid Metabolism (CAM) photosynthesis (Guerrero et al., 2019). Although *Selenicereus undatus* itself lacks a fossil record, it clearly inherits these specialized traits from ancestral cacti that first colonized dry environments.

Figure 5

Packrat Midden Containing Cactus Spines and Seeds.

Note. Image acquired from National Park Service, (National Park Service, 2025). It shows middens that offer indirect paleobotanical evidence of cactus-family plants in dry ecosystems where fossilization is rare (American Museum of Natural History, 2020).

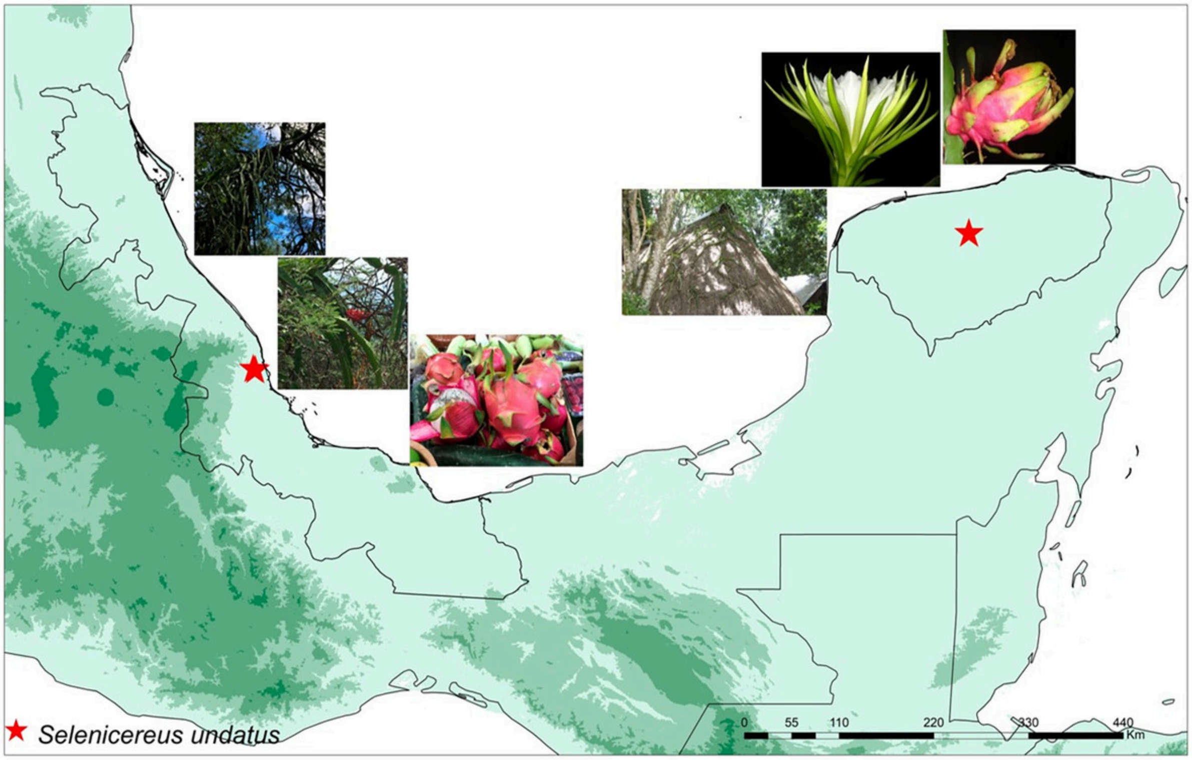
2.2.1 Origin of *Selenicereus undatus*

Selenicereus undatus, commonly known as dragon fruit, originated in Mesoamerica, primarily in regions extending from southern Mexico through Guatemala, Belize, and Honduras (CABI, 2021). Within its native range, seen in **Figure 6**, the species grows naturally as a climbing cactus that anchors itself to trees and rocks with aerial roots, an adaptation to warm, seasonally dry forests (CABI, 2021). These ecosystems are defined by alternating wet and dry periods, shaping the plant's physiology over time. Its succulent stems allow efficient water storage, while its nocturnal flowers, pollinated by bats and moths, minimize water loss and align with nighttime pollinator activity (Guerrero et al., 2019). Such ecological traits demonstrate how *Selenicereus undatus* evolved to survive under fluctuating water availability typical of tropical dry forest environments (Arakaki et al., 2011).

Human interaction with the species dates back centuries. Archeobotanical and historical evidence suggests that Indigenous peoples in Mesoamerica cultivated or at least managed wild populations of dragon fruit for food and ceremonial use long before European contact (CABI, 2021). Pre-Colombian trade routes connecting Central America with the Caribbean helped spread the plant beyonds its native habitat. By the late 19th century and early 20th century, the species had been introduced to tropical regions outside the Americas, including Southeast Asia (Crane & Balerdi, 2023). In modern-day Vietnam, Thailand, and China have become leading producers, yet the highest genetic diversity of *Selenicereus undatus* remains within southern Mexico and northern Central America, identifying this zone as the plant's center of origin (CABI, 2021) (Thompson et al., 2024).

Figure 6

Native Range of Selenicereus undatus



Note. Photo amended from PeerJ Life & Environment, (Oltehua-López et al., 2023). Depicts the plant's range extending from southern Mexico to northern Central America. These regions represent the natural habitat where the species evolved before its global cultivation.

2.2.2 Current Distribution and Production

Today, *Selenicerus undatus* is cultivated throughout most tropical and subtropical regions of the world, making it one of the most widely distributed members of *Cactaceae* (Crane & Balerdi, 2023). As Jing Zang, a Professor in the Department of Sociology and Director of the Faculty of Social Sciences at Peking University, mentions in "Produce Report" a website with news and analyses on China's market, the largest commercial producers are Vietnam and China, which account for the majority of international exports (Zang, 2025). Additional to that, as seen in **Figure 7**, production occurs in Thailand, Indonesia, India, Colombia, and Nicaragua, as well as in the southern United States, particularly Florida and Hawaii (Crane & Balerdi, 2023). Its rapid growth rate, drought tolerance, and ability to bear fruit within two years of planting contribute to its agricultural success (CABI, 2021). The fruit's high economic value and health-related appeal have driven expansion in both Asian and American markets (Zang, 2025).

The food and agriculture organization of the United Nations (FAO) formally includes the species under the Codex Standard for Pitahayas (CXS 237-2003), which establishes global quality and trade criteria (Food and Agriculture Organization of the United Nations & World Health Organization, 2003). In China alone, cultivation exceeds 53,000 hectares, producing approximately 1.6 million metric tons annually, as can be seen in **Figure 8** (Zang, 2025). Global demand continues to rise due to the fruit's nutritional properties and aesthetic market appeal (Crane & Balerdi, 2023). Although *Selenicereus undatus* now grows far beyond its native Mesoamerican range, it remains dependent on conditions similar to its natural habitat: warm temperatures, seasonal rainfall, and well-drained soils (CABI, 2021). The species' present distribution therefore reflects both long-term ecological adaptation and extensive human-driven cultivation (Guerrero et al., 2019).

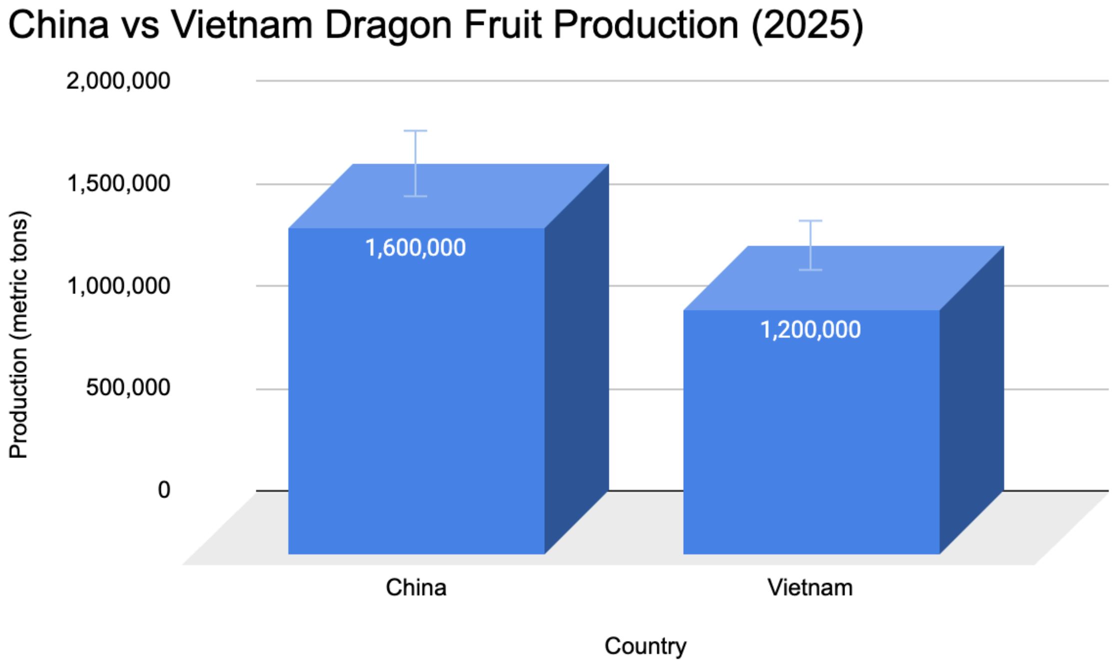
Figure 7

Global Production Areas of Selenicereus undatus

Note. Image extracted from Research Gate, (Chen, 2024). It depicts a map of major dragon Fruit production regions, with India and Vietnam being top producers.

Figure 8

Graph of Production Rates of Dragon Fruit in China and Vietnam



Note. Data information acquired from Produce Report (Zang, 2025). The graph highlights the production rates of the highest dragon Fruit producers worldwide.

2.3 Ecoregion and Climate of *Selenicereus undatus*

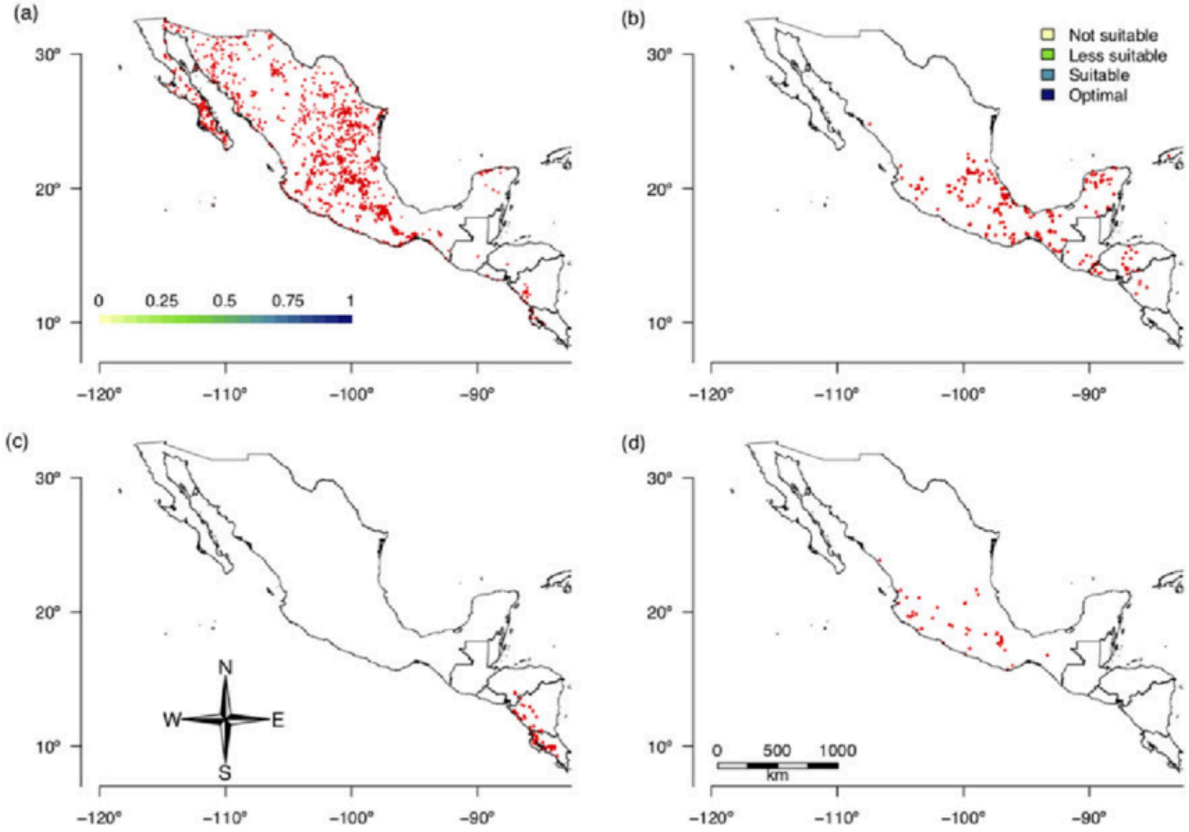
2.3.1 Ecoregion

The species *Selenicereus undatus* is native to the seasonally dry tropical forests of southern Mexico through to Honduras, as **Figure 9** shows, where environments, as described in the distribution above, are characterized by a distinct dry season lasting several months, a deciduous canopy that, as seen in **Figure 10**, periodically opens the understorey (a layer of vegetation beneath the main canopy of a forest) for enhanced irradiance, and generally well-drained soils on slopes, limestone outcrops or forest margins (Royal Botanical Gardens, Kew, 2017). Ecological niche modelling confirms that this plant is strongly associated with dry to semi-dry tropical lowland forests rather than permanently moist rainforests (Oltehua-López et al., 2023). Further modelling shows that temperature seasonality, precipitation seasonality and host tree availability (for climbing) are among the most important predictors of its native distribution (Sosa et al., 2020). In such ecosystems, the combination of a dry season and periods of high light that appear to favor climbing hemiepiphytic (grows on another plant for support) or lithophytic (grows on rocks) growth forms such as *Selenicereus undatus* (Andrade et al., 2006).

Within this ecoregion, the plant often occupies a mid-slope to edge niche rather than deep forest understorey, taking advantage of elevated drainage and access to supports (CABI, 2019). Although juvenile plants may tolerate partial shade, mature individuals exploit vertical supports such as trees, shrubs, and rocks to climb into brighter zones where fruiting is more successful (NC State Plant Toolbox, 2020). As the horticultural profile indicates, *Selenicereus undatus* prefers bright direct sunlight and warm environments, making it suited to tropical dry forest margins (NC State Plant Toolbox, 2020). As shown in **Figure 11,** these preferences reflect the eco regional dynamics of deciduous tropical dry forests: during the dry season, leaf drip increases light availability and conditions open for climbing and fruiting (Oltehua-López wt al., 2023). The toposequence (rocky slope, edge, support tree) thus plays a key role in the ecological placement of this species, helping to explain its absence from poorly drained valley bottoms, water-logged soils or closed canopy evergreen forests (Sosa et al., 2020).

Figure 9

Habitat Suitability Map for Dragon Fruit in Mesoamerica (Ecological Niche Model)



Note. Graphs taken from ResearchGate (Gutiérrez-Rodriguez, 2020). It shows a color-coded ecological niche model predicting areas of high climatic suitability for *Selenicereus undatus* across Mexico and Central America. Warmer tones indicate optimal conditions in seasonally dry tropical forests, illustrating how ecoregion and climate shape the species' natural distribution.

Figure 10

Wild Selenicereus Species in Seasonally Dry Forest, Oaxaca, Mexico

Note. Image used from ResearchGate (Bárdenas, 2015). It shows *Selenicereus undatus* growing epiphytically on trees in Oaxaca's seasonally dry tropical forest. The image highlights the plant's climbing habit and adaptation to dry, open woodland conditions typical of its native ecoregion.

Figure 11

Wild Dragon Fruit Plant in Deciduous Dry-Forest Vegetation

Note. Picture retrieved from USDA Plants Photo Gallery (Starr, 2012). It depicts a naturalized *Selenicereus undatus* growing among drought-deciduous vegetation, and illustrates its preference for high light, well-drained soils, and semi-open forest structure, representative of the species' native ecoregion in Mesoamerica.

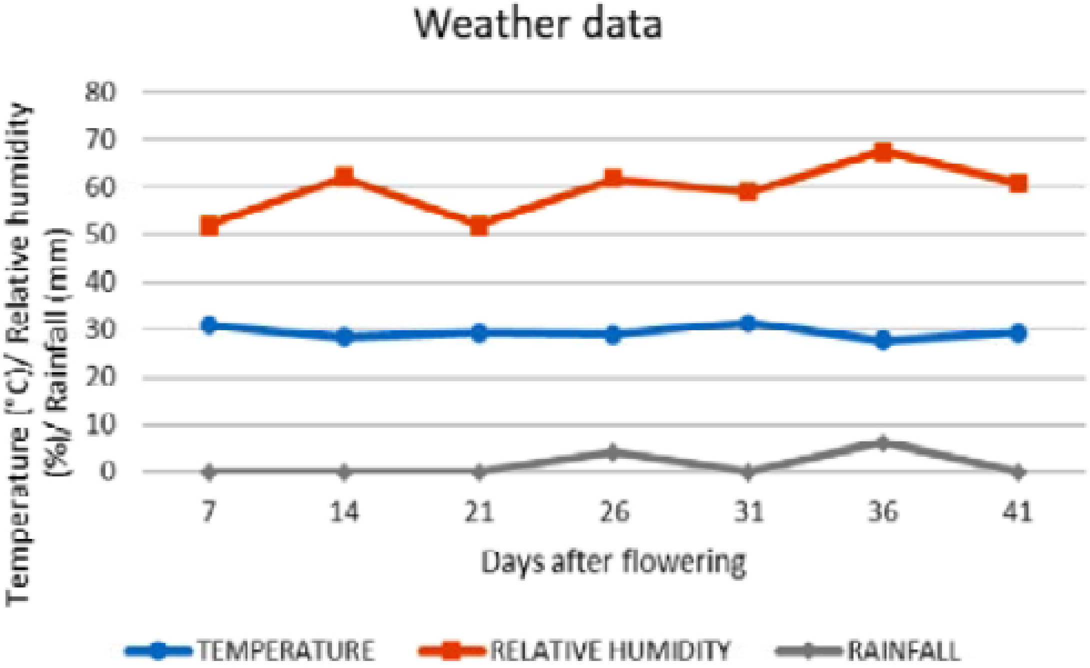
2.3.2 Climate and Growth

The climate of the native ecoregion is characterized by warm year-rounds temperatures, typically avoiding frost, with a marked wet season followed by a pronounced dry season combined with sufficient irradiance during the growth period (Richardson & Hodel, 2015). For *Selenicereus undatus*, modelling indicates that optimal growth correlates with environments where seasonal changes in precipitation and temperature provide a climate niche it can exploit (Sosa et al., 2020). The species has been shown to be a non-facultive CAM (crassulacean acid metabolism) plant, meaning it consistently uses noctural CO2 uptake and daytime stomatal closure to conserve water even when well-watered (Wang & Zhang, 2019). This physiological adaptation to drought and dry-season conditions underlies its success in seasonally dry tropical forest climates (Andrade et al., 2006).

Nevertheless, there are growth constraints linked to climate and site conditions. Frost events (temperatures near or below 0 degrees celsius) severely limit establishment outside its native range, as the plant lacks cold tolerance (Richardson & Hodel, 2015). Poor drainage and water-logging are similarly limiting, as root hypoxia and stem rot increase under saturated soils (Kakade et al., 2025). Deep shade under closed canopies restricts flowering and fruiting because light becomes limiting for the climbing habit and CAM productivity (Wang & Zhang, 2019). When considering colonization of new areas, the combination of warm climate, seasonal dryness, points of high light availability, vertical supports and well-drained soils dictates where establishment succeeds (Oltehua-López et al., 2023). Thus, the ecoregion-climate framework (toposequence of slope/edge, light regime, dry-season stress, support structures) is central both to navigate growth and expansion potential of *Selenicereus undatus* (Sosa et al., 2020).

Figure 12

Temperature, Relative Humidity, and Rainfall During Fruit Development in Selenicereus undatus



Note. Figure extracted from the Journal of Horticultural Sciences (Journal of Horticultural Sciences, 2022). It illustrates the relationship between average temperature, relative humidity, and rainfall across 41 days after flowering in *Selenicereus undatus*. The data demonstrate that fruit development occurs under stable warm temperatures (27–30 °C), moderate humidity (50–70%), and low rainfall, conditions typical of seasonally dry tropical forests. These climatic factors directly influence the species' reproductive success and highlight its adaptation to warm, frost-free, and well-drained environments discussed in the climate section.

2.4 Soils and Geology

2.4.1 Soil Characteristics and Nutritional Suitability

The edaphic composition of the habitats where *Selenicereus undatus* develops plays a decisive role in determining its distribution, physiology, and productivity. As a xerophytic (a plant adapted for life and growth with a limited water supply) native to the tropical dry forests of Mesoamerica, this species have evolved to thrive in soils that mirror its ecological origins: moderately fertile, well-drained substrates that balance moisture availability with aeration. The soil profile in these environments if often shaped by volcanic or calcareous parent materials, producing sandy-loam textures with sufficient mineral reserves and low salinity. Because *Selenicereus undatus* relies on Crassulacean Acid Metabolism (CAM) to regulate wat6er loss, the properties of its substrate must allow quick drainage while retaining just enough humidity to sustain photosynthesis during prolonged dry seasons. **Table 2** summarizes the primary soil characteristics that enable optimal growth for this species, integrating physiochemical properties with their ecological significance.

Table 2

Soil Preferences and Characteristics of Selenicereus undatus

SOIL PROPERTY	PREFFERED CONDITION	ECOLOGICAL FUNCTION
pH (acidity/alkalinity)	Slightly acidic to neutral (5.5-7.0)	Optimizes nutrient uptake and enzyme activity; extreme acidity reduces Ca and Mg availability.
Texture	Sandy loam to loam	Ensures both aeration and water retention; supports extensive root systems and drainage.
Porosity and Drainage	High porosity and well drained soils	Prevents root rot in epiphytic cacti; supports gas exchange necessary for CAM metabolism.
Organic Matter Content	Moderate to high	Improves soil structure, microbial activity, and water-holding capacity; key for nutrient cycling.
Depth	Deep (>60 cm)	Allows deep rooting and access to moisture during dry seasons
Salinity	Low	High salinity limits osmotic water uptake and damages cellular structures
Cation Exchange Capacity (CEC)	Moderate to high	*Enhances nutrient retention, particularly for* K^+, Ca^{2+}, *and* Mg^{2+} *ions*
Water Availability	Intermmitent but sufficient	*Supports CAM water conservation strategy and prevents desiccation*

Note. Data synthesized from (Oltehua-López et al., 2023), (Sosa et al., 2020), and (NC State Extension Plant Toolbox, 2020). Table shows the optimal soil parameters for *Selenicereus undatus* based on its physiology as a xerophytic, CAM-adapted cactus native to tropical dry forests.

2.4.2 Interpretation of Soil Properties

The soils that best support *Selenicereus undatus* balance aeration, drainage, and mineral availability, an ecological reflection of its adaptation to seasonallt arid, well-structured tropical soils. The slightly acidic to neutral pH (5.5-7.0) ensures that essential macronutrients such as phosphorus (P), magnesium (Mg), and Calcium (Ca) remain bioavailable, avoiding the toxic effects of aluminium (Al) saturation common in highly acidic profiles (Oltehua-López et al., 2023). At this range, microbial activity responsible for nutrient cycling also reaches its peal, maintaining a continuous release of minerals through organic decomposition (Sosa et al., 2020). Sandy-loam textures derived from weathered volcanic or calcareous materials provide de tual benefits of porosity and moisture retention, which are vital to maintaining water balance during the dry season (NC State Extension Plant Toolbox, 2020). The combination of coarse and fine particles ensures that excess water drains quickly while sufficient moisture remains available to support root function during prolonged dry periods. The high porosity of these soils those in **Figure 13**, like enables gas exchange, supporting the CAM characteristic of dragon Fruit, where stomatal opening occurs at night to conserve water (Kochian et al., 2015). This harmony between soil structure and plant physiology exemplifies how *Selenicereus undatus* has evolved not only to withstand but to depend on alternating periods of drought and rainfall to regulate its metabolic rhythm.

Equally significant is the organic matter content, which contributes to soil aggregation and serves as a nutrient reservoir through microbial decomposition. This organic layer improves soil structure and cation exchange capacity (CEC), allowing the retention of essential cations such as K^+ and Ca^{2+} that would otherwise leach through porous profiles (Guillén et al., 2023). In well-balanced soils, the decomposition of organic residues creates a slow but consistent nutrient supply, reducing dependence on external fertilization and minimizing nutrient loss (Shah et al., 2023). In deeper soils, which are those that exceeds 60 cm, roots can extend further to access stored moisture and minerals, a critical feature in the drought-prone ecoregions where *Selenicereus undatus* naturally thrives (Sosa et al., 2020). The structural stability of these deep profiles also helps prevent erosion during heavy rains, preserving fertility over long periods. Conversely, soils with high salinity or poor drainage compromise osmotic balance, hindering water absorption and leading to cellular dehydration that disrupts photosynthetic efficiency (Kokani et al., 2024). Over time, these stresses limit growth and fruit formation, illustrating why the most productive soils for *Selenicereus undatus* are those that achieve equilibrium between porosity, nutrient retention, and periodic moisture availability.

Figure 13

Dragon Fruit (Selenicereus undatus) Growing in Porous Soil

Note. Image ammended from Gardenered (Gardenered, 2019). The photo shows *Selenicereus undatus* developing in a well-drained, sandy-loam substrate typical of tropical dry forest cultivation, illustrating its preference for high aeration and moderate moisture retention (Shah, 2023).

2.4.3 Nutrient Requirements and Soil Interactions

Like most angiosperms, *Selenicereus undatus* requires a full complement of macronutrients (N, P, K, Ca, Mg, S) and micronutrients (Fe, Mn, Zn, Cu, B, Mo). However, multiple field and greenhouse studies have demonstrated that this species relies particularly on nitrogen and potassium to sustain vegetative expansion and high fruit production (Oltehua-López et al., 2023). Nitrogen supports the synthesis of chlorophyll and enzymes essential to maintaining the efficiency of CAM photosynthesis, allowing the plant to capture CO_2 at night while minimizing daytime transpiration (Sosa et al., 2020). In nitrogen-deficient soils, the plant exhibits chlorosis and reduced flowering, ultimately diminishing fruit yield. Potassium, in contrast, regulates stomatal function and osmoregulation(key processes that maintain internal water balance under arid conditions) and is also essential for sugar translocation to developing fruits (Fernandes et al., 2018). Adequate potassium availability has been correlated with improved fruit firmness, coloration, and sweetness, making it one of the principal determinants of commercial quality (Kochian et al., 2015). Calcium contributes to cell wall rigidity and assists in mitigating saline stress, while magnesium, as the central atom of chlorophyll, ensures the stability of photosynthetic pigments during prolonged exposure to sunlight.

The soils where *Selenicereus undatus* prospers are therefore those capable of supplying steady but not excessive nutrient levels, maintaining a natural balance aligned with its slow but steady metabolic rhythm. This is often achieved in soils with moderate CEC and sufficient organic matter, which act as nutrient buffers during alternating wet and dry seasons (Guillén et al., 2023). Organic compounds and soil microorganisms play a regulatory role in this system, releasing nutrients through mineralization when moisture returns after drought (Shah et al., 2023). Excessive fertilization or poor drainage, however, disrupts this balance by promoting leaching and creating anoxic conditions that reduce nutrient uptake efficiency (Kokani et al., 2024). When nitrogen and potassium ratios become disproportionate, vegetative growth may occur at the expense of reproductive development, reducing overall yield (Oltehua-López et al., 2023). Ultimately, *Selenicereus undatus* thrives in mineral-rich yet balanced soils, those that are capable of supporting root aeration, steady nutrient cycling, and intermittent hydration. This delicate equilibrium reflects the plant's evolutionary adaptation to its native edaphic and climatic conditions, enabling it to transform scarcity into an ecological advantage through resilience, efficiency, and optimized metabolism.

2.5 Light, Temperature, and Water

2.5.1 Light Regime

The climbing cactus *Selenicereus undatus* thrives in habitats where light is plentiful yet filtered by vegetation or rock structures that moderate intensity, reflecting its natural epiphytic and lithophytic adaptations, which were talked about more in depth in previous sections. It performs best under full to partial sunlight, requiring at least six hours of bright light per day to maintain balanced growth (LetPlant, 2024). The plant's photosynthetic mechanism follows the CAM pathway, where stomata open during the night for CO_2 intake and close during the day to conserve water (Oltehua-López et al., 2023). This unique system allows it to thrive under strong light conditions without experiencing excessive water loss. The stems' waxy cuticle and ribbed shape reduce surface area exposed to direct radiation, minimizing photoinhibition while maintaining effiencient light capture. When cultivated under artificial conditions, growers often supplement with full-spectrum LED light to replicate natural irradiance levels, especially during seasons of lower sunlight (Johnstone, 2025). Excessive shade, however, can limit chlorophyll production and reduce flowering rates, since light intensity directly affects the plant's photsynthetic enzyme activity and carbohydrate accumulation.

Under high photon flux, the metabolic rate of *Selenicereus undatus* increases significantly, leading to higher nutrient requirements such as N, P, and K. Nitrogen supports chlorophyll synthesis and enzyme activity essential for light capture, phosphorus contributes to ATP formation that drives photosynthesis reactions, and potassium regulates stomatal function and osmoregulation durin high irradiance (Ganesan et al., 2025). Studies have shown that a nutrient balance between these three elements, such as that of a radius of 440:300:650 (N:P:K) grams per pillar anually yields the most vigorous gorwth and fruiting (Ganesan et al., 2025). Moreover, Mg plays a supporting role in chlorophyll structure, enhancing the plant's capacity to utilize intense light efficiency (Panay News, 2017). Thus, the interaction between light and nutrition in *Selenicereus undatus* represented a fine equilibrium: sufficient in light drives photosynthetic demand, while adequate nutrient availability ensures that absorbed energy is effectively converted into growth and fruit production.

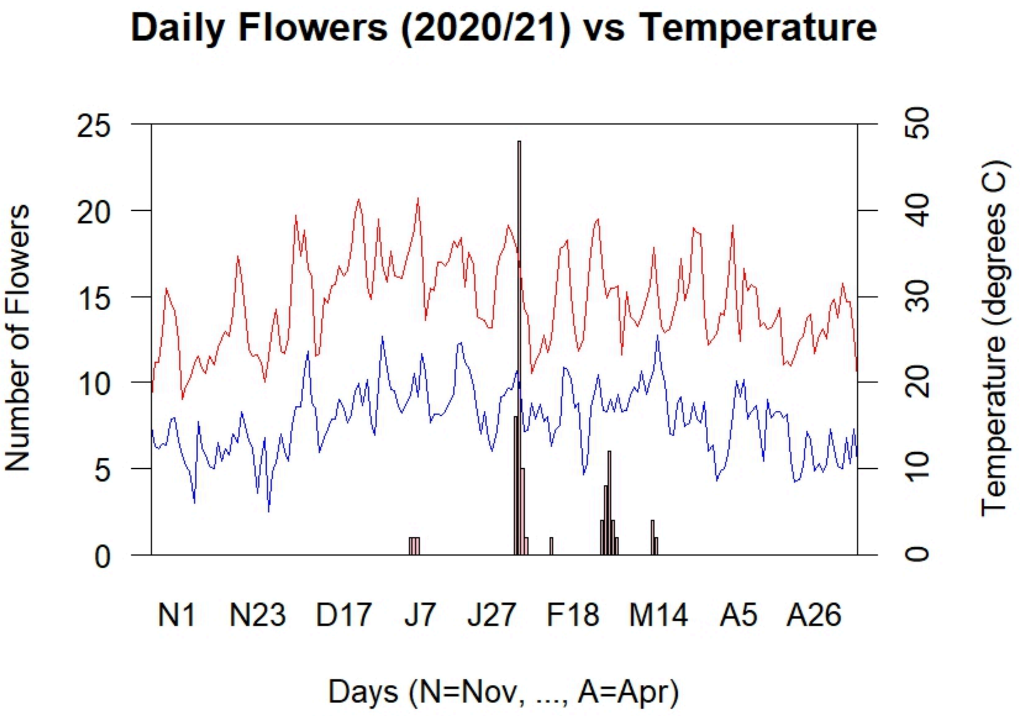
2.5.2 Temperature regime

The temperature requirements of dragon fruit closely match its tropical and subtropical origins, with optimal growth between 18-29 °C and tolerance down to 10°C at night (Gardenia, 2025). Photosynthesis and fruit formation are highly sensitive to temperature fluctuations, as low temperatures slow enzymatic reactions and high temperatures can damage repodructive tissues through heat stress. The cactus' mucilaginous parenchyma (the plant tissue composed of parenchyma cells that are specialized for storing a gelatinous substance called mucilage) and thick epidermis act as natural thermal buffers, stabilizing internal water potential and preventing tissue desiccation during heat waves (Sosa et al., 2020). In contrast, cold exposure below 7 °C may cause chilling injury, disrupting membrane fluidity and reducing chlorophyll flourescence (LetPlant, 2024). These physiological features highlight the plant's adaptation to thermally stable ecosystems: areas where day-night temperature variation enhances CAM activity, enabling nocturnal CO_2 fixation under cooler conditions and daytime carbohydrate production when temperatures rise.

Temperature also governs nutrient mobility and uptake efficiency within the plant. Warm soil temperatures promote faster ion diffusion and root absorption, particularly for mobile nutrients such as nitrogen and potassium. Research indicates that applying nutrients during periods of hight temperature correlates with increased uptake rates and improved yield quality (Sosa et al., 2020). Conversely, during cooler phases, slower root metabolism can limit nutrient transport, requiring adjustments in fertilizer schedules to prevent nutrient lockout. Among macronutrients, nitrogen is critical for protein synthesis and photosynthetic enzyme activity, while potassium enhances thermal resilience by maintaining osmotic balance and activating antioxidant enzymes that mitigate heat-induced oxidative stress (Ganesan et al., 2025). Phosphorus supports flowering and fruit development under favorable temperatures, and Ca strengthens cell walls against temperature induced expansion or contraction. The temperature regime of *Selenicereus undatus* thus interacts directly with its nutritional physiology, where optimal thermal conditions, as show in **Figure 14**, not only sustain enzymatic reactions but also facilitate the assimilation of nutrients essential for continued metabolic activity.

Figure 14

Daily Flower Production of Selenicereus undatus in Relation to Temperature (2020–2021)



Note. Graph taken from Journal of Arid Environments (Journal of Arid Environments, 2021). It shows Flowering frequency of *Selenicereus undatus* recorded between November 2020 and April 2021, showing highest bloom rates at 22–30 °C.

2.5.3 Water Regime and Hydric Balance

Although *Selenicereus undatus* originates from semi-arid regions, it demonstrates a need for moderate but consistent water supply, with annual precipitation of around 600-1,200 mm being ideal (Valadares et al., 2020). Its succulent stems act as living reservoirs, storing water to sustain metabolism during prolonged dry intervals. The CAM photosynthetic cycle allows the plant to minimize transpiration by closing stomata during the day, maintaining water-use efficiency even under intense solar radiation (Oltehua-López et al., 2023). Nonetheless, the plant's shallow root system demands well-drained soils, as excessive humidity or standing water can quickly lead to root rot (NCSU Plant Database, 2020). This makes water management a defining factor of its cultivation success: irrigation must mimic natural tropical rainfall patterns, meaning those of deep, sporadic water followed by periods of drying in order to maintain optimal root aeration and avoid anaerobic stress.

Water also serves as the medium for nutrient transport, meaning that irrigation practices must be synchronized with fertilization to prevent nutrient deficiencies or toxicity. During active growth, adequate moisture ensures efficient absorption of N, P, and K ions, while overwatering can cause nutrient leaching and oxygen depletion around the roots (Panay News, 2017). Potassium is essential in this hydric context because it helps maintain turgor and stomatal control, ensuring that even during mild drought, water is efficiently conserved (Ganesan et al., 2025). Calcium and magnesium also play crucial roles, stabilizing cell membranes and supporting photosynthetic balance during hydration changes (Bozhurin, 2024). Therefore, as seen in **Table 3**, the water regime of *Selenicereus undatus* cannot be isolated from its nutritional and climatic context: adequate water facilitates nutrient uptake, nutrients strengthen the plant’s water-use efficiency, and environmental factors such as light and temperature dictate how effectively the plant can balance these internal and external pressures.

Table 3

Optimal Environmental and Nutrient Conditions for Selenicereus undatus

FACTOR	OPTIMAL RANGE	IMPORTANCE	SOURCE
Light intensity	6-8 hrs full sun (12-14 hrs artificial sunlight	Promotes chlorophyll and flowering; partial shade prevents stress	(LetPlant, 2024) (Johnstone, 2025)
Day temperature	18-29 °C	Maintains enzymatic stability for CAM photosynthesis	(Sosa et al., 2020) (Gardenia, 2025)
Night temperature	10-20 °C	Cooler nights enhance CO_2 uptake and bud formation	(Sosa et al., 2020)
Annual rainfall	650-1,200 mm/year	Needs good drainage; excess humidity causes root rot	(NCSU Plant Database, 2020)
Soil texture	Porous, sandy-loam, pH 5.5-7.0)	Prevents waterlogging and nutrient lock-up	(Valadares et al., 2020)
Secondary nutrients	Mg and Ca	Mg for chlorophyll; Ca for tissue strength	(Ganesan et al., 2025)
N:P:K ratio	About 400:300:650 g/pillar/year	High K boosts fruit size and sugar content	(Bozhurin, 2024)

Note. Table amended from Dragon Fruit Life Cycle (Bozhurin, 2024). The table shows the conditions for the growth and fruiting of *Selenicereus undatus*. Values are averages from horticultural studies and open-access databases that are adapted together from these sources; they may vary slightly with climate and soil composition.

3.0 Biology

3.1 Chromosome Complement

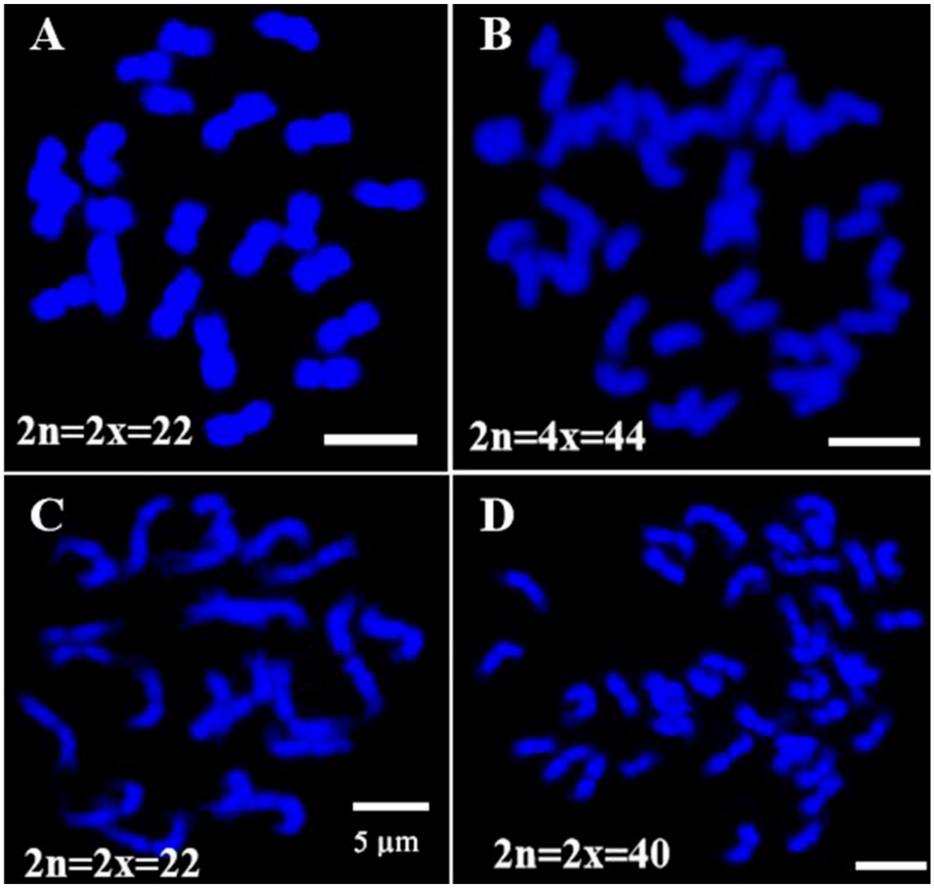
The chromosome complement of *Selenicereus undatus* provides essential insight into its genetic organization, evolutionary history, and reproductive behavior. Cytogenetic studies place the species within the broader chromosomal framework of the Cactaceae, a family characterized by relatively conserved chromosome numbers despite extensive morphological and ecological diversification. Most members of the tribe Hylocereeae, including *Selenicereus undatus*, exhibit a diploid chromosome number of 2n=22, which corresponds to a basic chromosome number of n=11 (Cisneros et al., 2011). This chromosomal stability suggests that speciation within the group has relied more heavily on ecological specialization and reproductive isolation than on large-scale chromosomal rearrangements. The maintenance of stable diploid complement is particularly relevant given the plant's wide geographic distribution and its transition from wild populations to intensive agricultural systems (Cisneros et al., 2011).

At the structural level, the chromosomes of *Selenicereus undatus* are small and mostly metacentric (which means having the centromere medially situated so that the two chromosomal arms are of roughly equal length) to submetacentric, a configuration commonly reported in cactus karyotypes and associated with genomic stability (Weiss-Schneeweiss & Schneeweiss, 2012). Karyotype analyses indicate a relatively symmetrical chromosome set, with limited size variation among homologous pairs. This symmetry is often interpreted as an ancestral condition, reinforcing molecular evidence that places *Selenicereus* within an early-diverging lineage of epiphytic cacti adapted to climbing growth forms rather than extreme desert specialization.

Cytological observations further suggest that chromatin organization in *Selenicereus undatus* supports regular meiotic pairing, which is consistent with its high pollen viability and successful fruit set under both natural and cultivated conditions, topics that will be explored further in later reproductive sections. A representative karyotype illustrating the diploid chromosome number and morphology of *Selenicereus undatus* is shown in **Figure 15**.

Figure 15

Karyotype of Selenicereus undatus (2n=22)



Note. Photo acquired from Plant Genetics, Epigenetics, and Chromosome Biology (Harun et al., 2024). It shows a representative karyotype showing the diploid chromosome complement of *Selenicereus undatus,* composed of 11 homologous chromosome pairs with predominantly metacentric and submetacentric morphology. The small chromosome size and overall symmetry are characteristic of members of the tribe *Hylocereeae* and support cytogenetic stability within cultivated and wild populations (Harun et al., 2024).

3.2 Life Cycle and Phenology

3.2.1 Life Cycle

The life cycle of *Selenicereus undatus* is perennial and cyclic, meaning that individual plants persist for many years and repeatedly alternate between vegetative growth and reproductive activity rather than completing a single, terminal cycle (Crane & Balerdi, 2024). New individuals may originate either from seeds or from vegetative stem cuttings, a distinction that has important developmental consequences. Seed-derived plants begin life as genetically unique individuals but must pass through a prolonged juvenile phase before flowering is possible. In contrast, cuttings originate from already differentiated stem tissue and therefore bypass early developmental constraints, allowing them to reach reproductive maturity faster (Rodríguez, 2025). Regardless of origin, the earliest functional phase of the life cycle is establishment, during which the plant prioritizes rooting and attachment rather than above-ground expansion. Dragon fruit produces adventitious roots, which are roots that emerge from stem tissue rather than from a primary root system. These roots anchor the plant to supports and enable water and nutrient uptake, reflecting the species' climbing, hemiepiphytic growth habit (Crane & Balerdi, 2024). Successful establishment is a prerequisite for all later life cycle stages and directly influences long-term productivity.

Once established, the plant enters a juvenile vegetative phase characterized by rapid elongation of flattened stems known as cladodes. Cladodes are photosynthetic organs that replace true leaves, which are reduced and transient in cacti (Belbase, 2025). Along the margins of each cladode are areoles, specialized structures unique to cacti that function as localized growth centers. At this stage, areoles are strictly vegetative, meaning they can produce new shoots or roots but are physiologically incapable of forming flowers. As the plant accumulates vegetative biomass and cladodes age, some areoles become competent, a term that refers to their ability to respond to environmental signals that trigger reproduction (Belbase, 2025)Importantly, competence is tissue-specific rather than uniform across the entire plant: older cladodes may be capable of flowering while younger ones remain juvenile (Kishore, 2016). This transition marks the mature vegetative stage, in which the plant possesses both the structural capacity and the stored resources necessary to support reproduction.

Reproductive development begins with flower induction, the physiological process by which competent vegetative buds are irreversibly committed to floral development. In *Selenicereus undatus,* induction is strongly influenced by photoperiod, or the relative length of day and night, with long-day conditions generally favoring floral initiation (Kishore, 2016). Temperature and management practices such as pruning further modulate this response by altering resource allocation and bud availability. Following induction, flowering occurs in a highly synchronized and temporally restricted manner. Flowers are nocturnal, and anthesis (the period during which the flower opens and becomes active) typically lasts a single night. During this brief window, pollen is released and the stignma becomes receptive, making pollination both time-sensitive and vulnerable to ecological limitations (Rodríguez, 2025). Successful pollination leads to fertilization and fruit set, defined as the transition from flower to developing fruit. Some genotypes exhibit self-incompatibility, so they require cross-pollination to achieve fertilization. Once fruit set occurs, fruit growth and ripening proceed over approximately 25-32 days after anthesis, culminating in physiological maturity. After harvest, the plant returns to a mature vegetative stage, producing new cladodes that can later re-enter the reproductive cycle (Kishore, 2016). This capacity for renewal allows *Selenicereus undatus* to repeat the life cycle across multiple seasons and years. **Table 4** summarizes all the steps of the cycle previously mentioned.

Table 4

Overview of Life Cycle Stages in Selenicereus undatus

STAGE	DESCRIPTION	FUNCTION
Propagation	Establishment begins from sexually produced seeds or vegetative stem cuttings with pre-formed areoles.	Determines genetic variability, time to maturity, and uniformity of subsequent growth.
Establishment	Development of adventitious roots and attachments.	Anchors the plant and enables water and nutrient uptake necessary for later canopy expansion.
Juvenile growth	Cladode elongation; non-reproductive areoles.	Builds photosynthetic capacity and carbohydrate reserves required for flowering.
Mature canopy	Competent areoles on older cladodes.	Marks the transition from purely vegetative growth to potential reproductive activity.
Flower induction	Photoperiod (and environment) driven bud commitment.	Initiates the reproductive phase and regulates flowering timing and intensity.
Anthesis	Rapid flower opening during a single night. Stigma receptivity and pollen release are temporarily constrained.	Creates a narrow window for successful pollination.
Pollination and Fruit Set	Succesfull pollen transfer and fertilization.	Acts as the main control for reproductive success.
Fruit Growth and Ripening	Ovary enlargement, seed development and peel color change over 25-32 days after anthesis.	Produces mature fruit and completes one reproductive cycle.
Renewal	Continued cladode production following fruiting.	Allows repeated flowering and fruiting cycles across mutiple years.

Note. Table made based on information from the Department of Earth and Environment (Belbase, 2025). It shows the life cycle stages as conceptual sequences for *Selenicereus undatus* (Kishore, 2016).

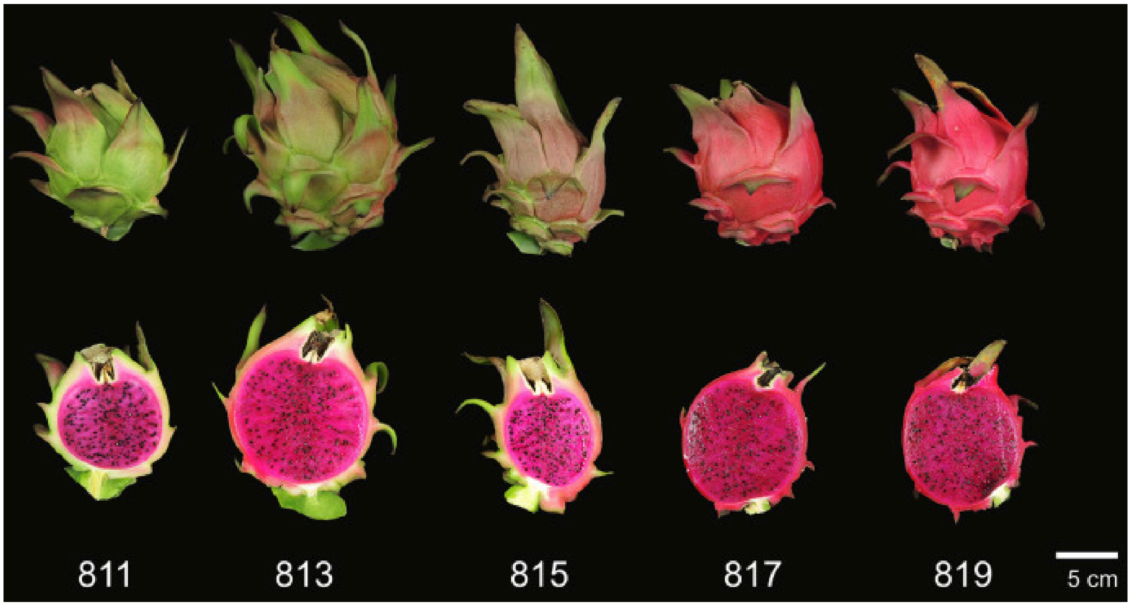
3.2.2 Phenology

Phenology in Selenicerus undatus refers to the seasonal timing and recurrence of developmental events, particularly vegetative growth, flowering and fruiting, in relation to environmental conditions (Weiss et al., 1994). Unlike the life cycle, which describes the sequence of biological stages, phenology emphasizes the time, the moment when those stages occur and how consistently they repeat over time. Dragon fruit exhibits a strongly seasonal reproductive phenology, with flowering concentrated in defined periods of the year rather than occurring continuously (Weiss et al., 1994). In most tropical and subtropical regions, flowering is initiated during warmer months when day length increases, reflecting the species' sensitivity to photoperiod as a temporal cue (Crane & Balerdi, 2023). Vegetative growth, by contrast may occur over a broader temporal window provided temperature and water availability remain adequates (Crane & Balerdi, 2023).

Flowering phenology in *Selenicereus undatus* is typically expressed as discrete flowering waves, rather than a single synchronized event (Weiss et al., 1994). Each wave consists of a rapid transition from floral bud emergence to anthesis, followed by a short interval before the next wave may occur (Weiss et al., 1994). This pattern results in asynchronous flowering within individual plants and across populations, as not all competent areoles respond simultaneously to inductive cues. Environmental conditions such as temperature fluctuations, rainfall patterns, and management practices can modify the number, timing, and intensity of these flowering waves (Crane & Balerdi, 2023). As a consequence, flowering phenoloogy is variable between years and locations, even when the underlying life cycle remains unchanged. **Figure 16** highlights the phenological progression of dragon fruit development, illustrating how flowering is followed by rapid and sequential changes in fruit growth and ripening over time.

Figure 16

Phenological Development of Selenicereus undatus



Note. Image amended from Scientia Horticulturae (Chu & Chang, 2022). It shows successive stages of dragon fruit development from early fruit formation to full ripeness, reflecting the short and predictable phenological interval between flowering and fruit maturity, which typically occurs 25-32 days after anthesis (Mizrahi et al., 2002).

3.3 Reproductive Biology

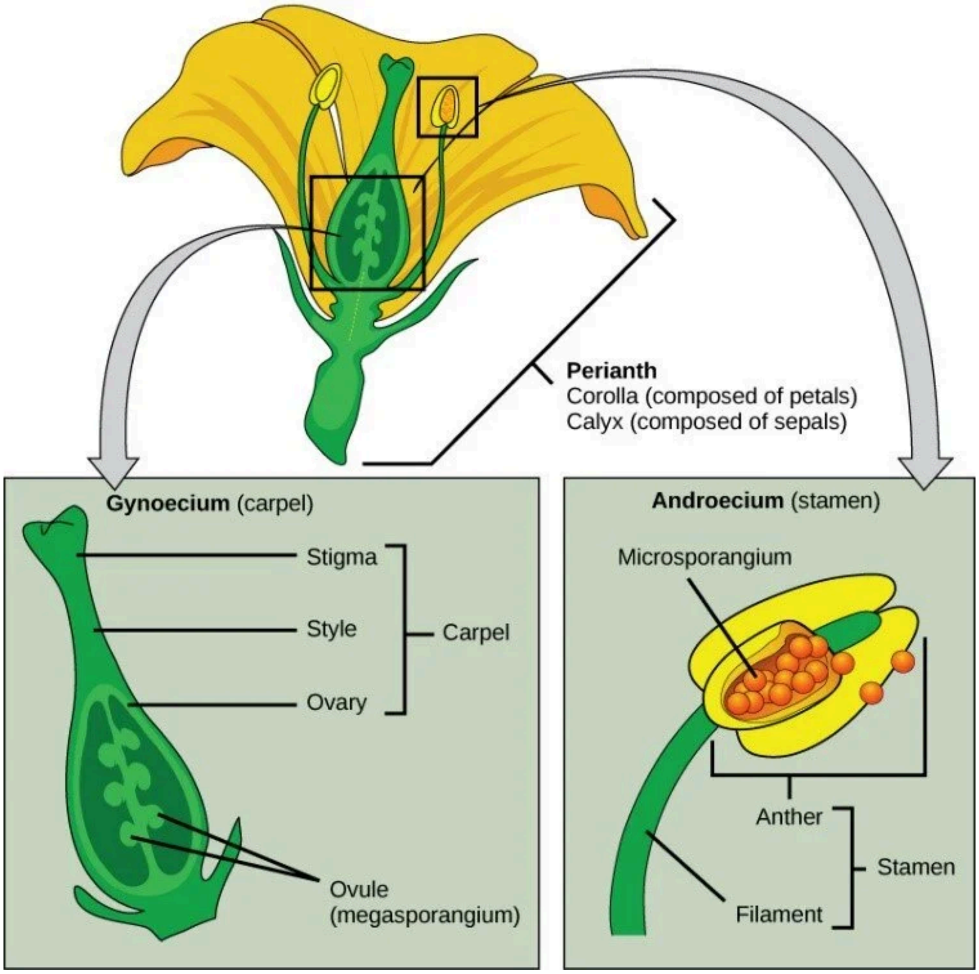
3.3.1 Sexuality

In flowering plants, sexuality refers to the ways in which male and female reproductive structures are arranged and expressed within individuals and populations (Barret, 2002). The fundamental unit of plant sexual reproduction is the flower, which can contain male structures (stamens that produce pollen), female structures (carpels that receive pollen and contain ovules), or both in the same floral unit (Peach et al., 2020) (Barret, 2002). Species, such as *Selenicerus undatus,* with flowers that contain both male and female parts are called hermaphroditic or bisexual; in these flowers, pollen and ovules are produced in the same individual flower, allowing self and cross pollination (Goldberg et al., 2017). This bisexual condition is by far the most common sexual system in angiosperms because it increases the chances of pollination when pollinators are scarce (Goldberg et al., 2017). As shown in **Figure 17**, the flowers of *Selenicereus undatus* are structurally bisexual, containing both functional stamens and a central pistil withinin the same floral unit, which allows a single flower to perform both male and female reproductive roles. By contrast, unisexual flowers are structurally male or female only, lacking either functional stamens or carpels, and are found in species with separate sexes on the same plant (monoecious) or on different plants (dioecious) (Jabbour et al.,, 2022). Monoecious species bear both male and female flowers on one individual, allowing cross pollination within a single plant, whereas dioecious species have individuals that are exclusively male of female, which forces outcrossing between separate plants (Machado et al., 2006).

Sexual systems in plants, such as hermaphroditism, monoecy, and dioecy, are linked with how plants balance reproductive success and genetic diversity in their environment (Barret, 2002). Hermaphroditic sexuality tends to promote flexibility because one flower can fulfill both sexual roles at different times or under different conditons, and in some species, flowers change function temporarily to maximize fertilization opportunities (Barret, 2002). In species with unisexual flowers, the separation of male and female roles helps avoid self-fertilization and promotes genetic diversity through cross pollination, particularly when pollinators are effective (Machado et al., 2006). These sexual systems vary widely across flowering plant lineages, and evolutionary shifts from one system to another (for example, from bisexual to diocecious sexual expression) are related to ecological pressures, genetic regulation, and developmental pathways that influence how reproductive organs develop and function (Jabbour et al., 2022). Because plant sexuality affects how genes flow through populations and how pollination operates, understanding these systems is essential for studying plant reproduction and evolution.

Figure 17

Bisexual Flower Structure in Angiosperms



Note. Diagram used from The Green Institute (THE GREEN INSTITUTE, 2024). It depicts a bisexual (hermaphroditic) flower containing both male reproductive organs (stamens, which produce pollen) and female reproductive organs (pistil, composed of stigma, style, and ovary) within the same floral unit. This arrangement reflects the sexual condition of *Selenicereus undatus*, whose flowers are also structurally bisexual and capable of performing both female and male reproductive functions within a single flower (Barret, 2002).

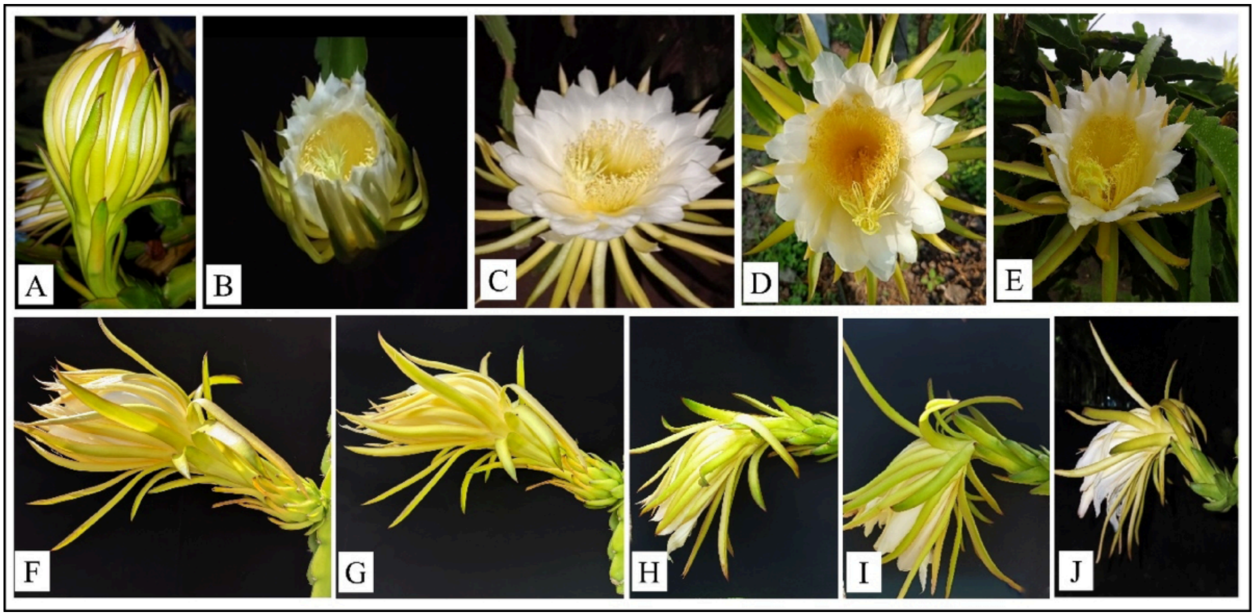
3.3.2 Floral Biology and Anthesis

The flowers of *Selenicereus undatus* are among the largest and most morphologically distinctive within the Cactaceae, reflecting strong specialization for animal-mediated pollination (Weiss et al., 1994). Florsal buds develop along mature cladodes and give rise to large. Solitary flowers that can exceed 25-30 cm in length when fully expanded (Weiss et al., 1994). Each flower consists of numerous petalooid tepals arranged in several whorls, with outer tepals typically greenish to yellow and inner tepals white, forming a long floral tube that encloses the reproductive organs (Weiss et al., 1994). The androecium is composed of hundreds of stamens distributed along the inner surface of the floral tube, while the gynoecium consists of a single elongated pistil terminating in a multi-lobed stigma positioned above the stamens (Weiss et al., 1994). This spatial arrangement facilitates pollen transfer by visiting animals and reduces physical interference between male and female functions during anthesis (Weiss et al., 1994). As illustrated in **Figure 18**, the floral structure of *Selenicereus undatus* clearly shows the elongated floral tube, abundant stamens, and centrally, positioned pistil that characterize its reproductive morphology and pollination strategy (Weiss et al., 1994).

Anthesis in *Selenicereus undatus* is strictly nocturnal and highly synchronized, typically beginning shortly after sunset and lasting for only a single night (Weiss et al., 1994). Flowers usually open rapidly in the evening, reaching full expansion within one to two hours, and begin to senesce by early morning of the following day (Weiss et al., 1994). During anthesis, both pollen release and stigma receptivity occur within the same night, creating a narrow but efficient window for successful pollination (Weiss et al., 1994). This short anthesis period is strongly associated nocturnal pollinators, particularly bats and moths, which are attracted by the flower's large size, pale coloration, and scent emitted during the night (Weiss et al., 1994). Environmental factors such as temperature and humidity influence the timing and success of flower opening, with warm nights and stable conditions favoring complete anthesis and higher fruit set (Weiss et al., 1994). The combination of large floral size, nocturnal anthesis, and synchronized reproductive orhan activity highlights he high degree of ecological specialization in the floral biology of *Selenicereus undatus* and sets the foundation for understanding its pollination mechanisms discussed in later sections (Weiss et al., 1994).

Figure 18

Floral Development and Anthesis Sequence in Selenicereus undatus



Note. Image taken from Scientific Reports (Jadhav et al., 2025). It documents the successive stages of floral development and anthesis in dragon fruit, from closed floral bud formation (A-B), through progressive tepal expansion during nocturnal opening (C-D), to full anthesi characterized by complete exposure of stamens and the centrally positioned pistil (E). Panels F through J illustrate lateral views of the flower before, during and after anthesis, showing the rapid opening process and subsequent wilting following the single-night flowering event. This sequence reflects the species' strictly nocturnal anthesis and short floral lifespan, traits associated with adaptation to night-active pollinators and efficient pollen transfer (Weiss et al., 1994).

3.3.3 Pollen, Pollination, and Potential Pollinators

The pollen of *Selenicereus undatus* is produced in large quantities by the numerous stamens that line the inner floral tube, a feature commonly associated with animal-pollinated flowers that rely on physical contact for pollen transfer (Weiss et al., 1994). Pollen grains are relatively large and sticky, characteristics that enhance adhesion to visiting pollinators and reduce loss during transport (Del Ángel-Pérez et al., 2023). Studies have shown that pollen viability in *Selenicereus undatus* is highest during the hours of nocturnal anthesis, coinciding with peak stigma receptivity, which maximizes the likelihood of successful fertilization within the short flowering window (Weiss et al., 1994). Although the species is structurally capable of self-pollination due to its bisexual flowers, natural fruit set is often low in the absence of effective pollen vectors, indicating a functional reliance on cross pollination for optimal reproductive success (Del Ángel-Pérez et al., 2023). This dependence highlights the ecological importance of pollen transfer efficiency rather than mere pollen production in determining reproductive output.

Pollination in dragon fruit is primarily associated with nocturnal animals, particularly bats and moths, as mentioned before. They are attracted by the plant's characteristics, especially by its abundant pollen reward. Bat pollination has been identified as especially effective due to the animal's ability to contact both stamens and stigma while foraging, facilitating large-scale pollen transfer between flowers and plants (Weiss et al., 1994). In regions where natural nocturnal pollinators are scarce or absent, flowers may still receive limited pollen transfer from insects or through manual pollination, but these alternatives generally result in lower fruit set and smaller fruit size (Weiss et al.,1994). As shown in **Figure 19**, the floral architecture of dragon fruit promotes direct contact with visiting pollinators during nocturnal visits. The interaction between pollen traits, flower structure, and pollinator behavior underscores the species' specialization for animal pollination and explains why pollinator availability plays a critical role in reproductive success and yield (Del Ángel-Pérez et al., 2023).

Figure 19

Pollination of Selenicereus undatus by Nocturnal Pollinators

Note. Picture amended from the Journal of Applied Ecology (Journal of Applied Ecology, 2020). This image illustrates nocturnal pollination in *Selenicereus undatus,* showing how visiting animals, in this case bats, contact the exposed stamens and central stigma while foraging. This interaction facilitates efficient pollen transfer during the brief anthesis period and supports cross pollination, which has been shown to increase fruit set and fruit quality compared to autonomous self-pollinaton (Weiss et al., 1994).

3.4 Fruit Development and Seed Set

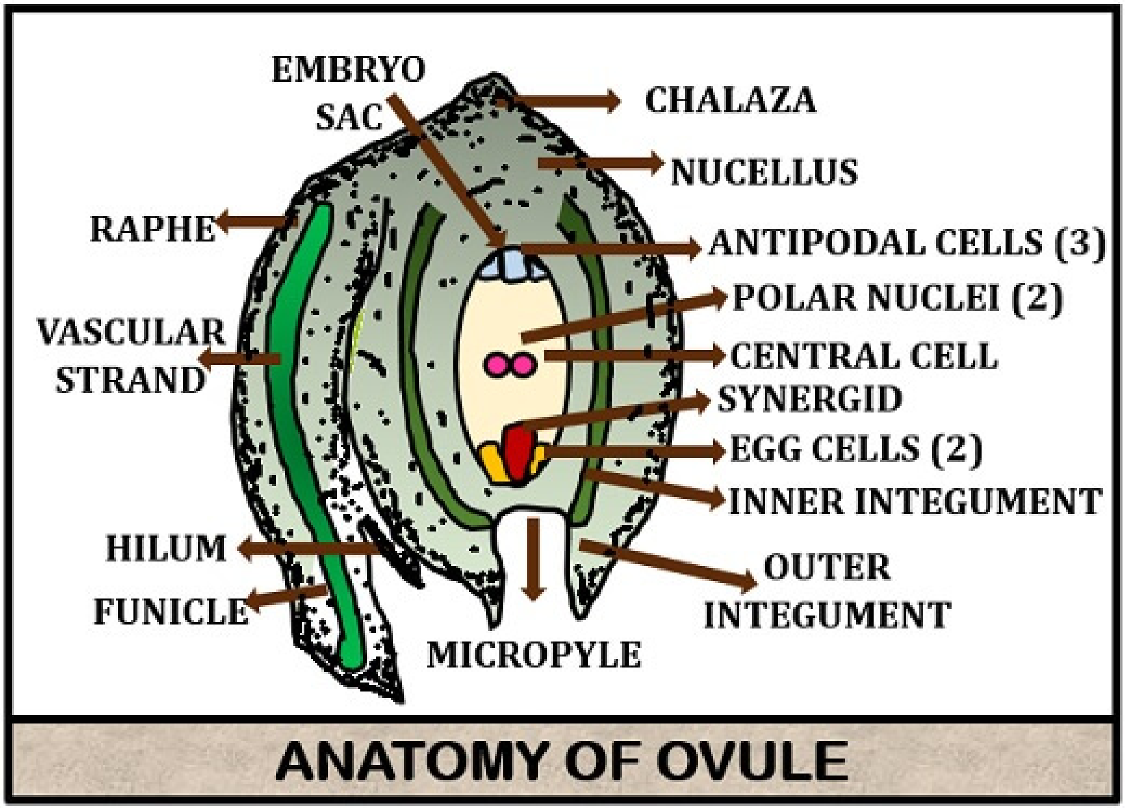
3.4.1 Ovule Development

Ovule development in *Selenicereus undatus* follows the general angiospem pattern but shows structural traits that are characteristic of the Cactaceae family, particularly in relation to the inferior ovary and placentation type. In this species, ovules originate from the placental tissue lining the inner ovary wall and begin differentiation shortly before anthesis, when the floral bud has reaced near full expansion (Weiss et al., 1994). Each ovule is anatropous, meaning it becomes inverted during development so that the micropyle faces the funiculus, a configuration that facilitates efficient pollen tube entry after fertilization (Kishore, 2016). The ovules are also bitegmic, possessing two integuments (the outer, protective covering layers of an organism or its organ) that later contribute to seed coat formation, and crassinucellate, meaning it has a well-developed nucellus that provides structural and nutritional support to the developing embryo sac (Machado, 2006). This ovule structure reflects an adaptation to enclosed ovary development and high ovule density.

As ovule maturation progresses, megasporogenesis occurs within the nucellus, where a single megaspore mother cell undergoes meiosis to produce four megaspores, of which only one remains functional (Kishore, 2016). This functional megaspore undergoes mitotic divisions to from the Polygonum-type embryo sac, the most common embryo sac type in flowering plants, consisting of eight nuclei organized into seven cells (Machado, 2006). In *Selenicereus undatus,* the spatial organization of the embryo sac is closely linked to the rapid post-anthesis fertilization window, as pollen tube growth and double fertilization typically occur within hours after successful pollination (Weiss et al., 1994). The high synchrony between ovule maturity and anthesis helps explain the species' high potential seed set under favorable pollination conditions (Weiss et al., 1994). **Figure 20** illustrates the anatomical organization of the ovule and the relative position of the integuments, nucellus, and micropyle during late pre-fertilization stages.

Figure 20

Structural Components of a Mature Anatropous Ovule



Note. Photo from Biology Reader (Supriya N, 2019). The diagram illustrates the structural components of a mature anatropous ovule, including the integuments, nucellues, embryo sac, and associated tissues such as the funicle, raphe, and vascular strand. The labeled organization highlights the spatial arrangement for the egg apparatus, central cell, and antipodal cells within the embryo sac, emphasizing features relevant to fertilization and subsequent seed development in flowering plants, including *Selenicereus undatus.* The orientation shown reflects the inverted position of the ovule that facilitates pollen tube entry through the micropyle.

Following fertilization, he ovules rapidly transition into seed primordia, with integument tissues differentiating into the protective seed coat while the zygote and endosperm initiate development (Kishore, 2016). Ovule abortion can occur when fertilization is incomplete or when resource allocation within the developing fruit becomes limiting, a phenomenon observed in *Selenicereus undatus* when pollination intensity is low or uneven (Weiss et al., 1994). However, under effective cross pollination, ovule-to-seed conversion rates are high, contributing to the large number of viable seeds characteristic of mature dragon fruit berries (Weiss et al., 1994). To summarize the key structural and developmental traits of ovules in dragon fruit, **Table 5** presents a concise overview of ovule type, orientation, and tissue differentiation stages relevant to seed formation.

Table 5

Structural and Developmental Characteristics of Ovules in Selenicereus undatus

FEATURE	DESCRIPTION
Ovule orientation	Anatropous
Integuments	Bitegmic (two integuments)
Nucellus type	Crassinucellate (a type of plant ovule characterized by a well-developed, thick nucellus, which offers protection)
Embryo sac type	Polygonum-type
Placentation	Parietal, along inner ovary wall
Post-fertilization fate	Differentiates into viable seeds under effective pollination

Note. Table with information from the American Society for Horticultural Science (Weiss et al., 1994). It synthesizes morphological and developmental characteristics of ovules in *Selenicereus undatus* by integrating general angiosperm embryological patterns with cactus-specific adaptations. Rather than listing isolated traits, the table emphasizes functional relationships between ovule anatomy and successful seed set under effective pollination conditions (Machado, 2006).

3.5 Ecophysiology

3.5.1 Germination

In *Selenicereus undatus*, seed germination is generally rapid once seeds are hydrated, which reflects an ecophysiological strategy adapted to warm environments where moisture availability can be brief and unpredictable (Ahmed, 2006). Temperature is one of the most influential factors controlling germination performance, with multiple studies, plus information shown in Chapter 2, reporting optimal germination around 25 °C or under alternating temperatures between 20 and 30 °C, conditions that promote enzymatic activity and embryo growth (Ruths et al., 2019). In contrast exposure to higher temperatures such as 35°C has been associated with reduced germination percentages and lower seed vigor, suggesting thermal stress limits early metabolic processes (Ruths et al., 2019). Light availability also plays a regulatory role as dragon fruit seeds are often described as positively photoblastic, meaning that exposure to light enhances germination responses (Ruths et al., 2019). This trait is consistent with broader cactus seed ecology, where light sensitivity prevents germination at excessive soil depths and increases the chance that seedlings emerge in favorable surface conditions (Ahmed, 2006). As a result, shallow sowing and stable surface moisture are key ecological requirements for successful germination (Ruths et al., 2019).

Beyond temperature and light, germination success in *Selenicereus undatus* is strongly influenced by substrate properties, particularly water retention and aeration, because its seeds are small and highly susceptible to surface desiccation (Sarwar et al., 2024). Comparative studies evaluating different growing media have shown that germination percentage and speed vary significantly depending on the physical traits of the substrate, with airy yet moisture-stable media consistently outperforming dense or waterlogged substrates (Sarwar et al., 2024). These early conditions also have lasting effects, as seedlings emerging from favorable germination environments often maintain higher growth performance during subsequent developmental stages (Sarwar et al., 2024). Additionally, physiological factors such as fruit maturity at seed harvest and the application of gibberellic acid (GA3) have bee shown to influence germination dynamics and early seedling development, indicating that dragon fruit seeds respond to hormonal and developmental cues even in the absence of strong dormancy mechanisms (Santos, 2022). However, propagation-focused studies emphasize that under warm and controlled conditions, the seeds can germinate effectively without complex pretreatments, provided that seeds are properly cleaned, briefly dried, and sown into a suitable micro-environment (Ahmed, 2006). The main germination drivers reported across studies are summarized in **Table 6**, which integrates environmental and physiological factors relevant to dragon fruit seed establishment.

Table 6

Environmental and Physiological Factors Influencing Germination in Selenicereus undatus

GERMINATION FACTOR	REPORTED PATTERN	ECOPHYSIOLOGICAL IMPLICATION
Temperature	Optimal germination at 25-30 °C. Reduced performance at 35°C.	Warm but non-extreme temperatures favor enzymatic activity and embryo development.
Light/Sowing depth	Seeds are positively photoblastic, with light enhancing germination.	Shallow sowing promotes germination by ensuring light exposure and rapid emergence.
Substrate / Growing media	Germination percentage and timing vary across media due to differences in moisture retention and aeration.	Moist but well-aerated substrates reduce desiccation while maintaining oxygen availability.
Seed handling	Seeds are separated from pulp and briefly dried before sowing.	Proper cleaning reduces microbial interference and supports uniform germination.
Hormonal cues (GA3)	GA3 concentration and fruit maturity influence germination and early growth.	Hormonal treatments enhane synchronization but are not essential in optimal conditions.

Note. Table made with information from Science of Plants and Derived Products (Ruths et al., 2019). It summarizes key enviornmental and physiological factors reported in open-access studies on dragon fruit germination, highlighting consistent trends in temperature sensitivity, light responsiveness, substrate effects, and seed physiology (Sarwar et al., 2024). Information is synthesized from experimental and propagation-focused research rather than a single dataset, reflecting general ecophysiological patterns across *Selenicereus undatus.*

4.0 Propagation and Management

4.1 Propagation

4.1.1 Natural and Vegetative Regeneration

Dragon fruit plants possess a strong regenerative capacity that allows them to recover and reproduce through vegetative structures. In natural environments, regeneration frequently occurs when segments of the succulent stems break off from the parent plant and fall onto a suitable surface where they can develop new roots and shoots, a process related to the stem cutting practices illustrated in **Figure 21** (Kakade et al., 2021). These stem fragments contain meristematic tissues capable of initiating rapid cell division, allowing the plant to generate adventitious roots when exposed to adequate moisture and temperature conditions (Kakade et al., 2021). This regenerative ability is particularly effective in climbing cacti such as *Selenicereus undatus,* whose elongated stems are naturally prone to mechanical breakage due to wind, wight, or contact with surrounding structures (Borchetia et al., 2022). Once detached segments establish contact with soil or organic substrates, they can quickly form roots and begin developing into independent plants that retain the genetic characteristics of the parent individual (Kakade et al., 2021).

Although sexual reproduction through seeds is possible, vegetative regeneration remains the dominant pathway through which dragon fruit populations expand in both natural and cultivated environments (Anushi et al., 2022). Seeds contained in the fruit can germinate when deposited in moist soil after the fruit decomposes or is dispersed by animals, but this process is generally slower and less reliable compared to vegetative propagation (Anushi et al., 2022). Seedlings require stable environmental conditions and longer developmental periods before reaching maturity, which limits their role in rapid plant establishment (Anushi et al., 2022). In contrast, vegetatively regenerated plants originate from mature tissue and therefore establish more quickly, allowing them to reach productive stages earlier than seed-grown individuals (Kakade et al., 2021). This biological characteristic explains why both natural ecosystems and agricultural systems rely heavily on vegetative regeneration as the primary mechanism through which dragon fruit plants maintain and expand their populations (Wilhelmi, 2019).

Figure 21

Stem Cutting Used for Vegetative Regeneration in Selenicereus undatus

Note. Photo amended from Epic Gardening (Hailey & Jay, 2024). It shows the collection of a dragon fruit stem segment intended for vegetative propagation. In *Selenicereus undatus,* detached stem sections are capable of developing adventitious roots once they are placed in suitable soil conditions. This regenerative ability allows new plants to develop from mature tissue, which enables faster establishment and maintain the genetic characteristics of the parent plants (Hailey & Jay, 2024).

4.1.2 Nursery propagation, Cuttings, and Planting Techniques

In agricultural production systems, dragon fruit is most commonly propagated in nurseries using vegetative cuttings obtained from mature and healthy stems. This method is preferred because it allows growers to reproduce plants that maintain the genetic characteristics of the parent plant while also reducing the time required for establishment and fruit production (Kakade et al., 2021). Stem cuttings are typically taken form mature segments measuring approximately 20-40 cm in length, ensuring that the selected tissue is free from disease and mechanical damage (Chakraborty, 2020). After cutting, the stem segments are usually left to dry for several days so that the wound can form a protective callus layer (Wilhelmi, 2019). This process reduces the risk of fungal infection and improves the success rate of root formation once the cutting is planted in soil (Wilhelmi, 2019). As seen in **Figure 22**, these cuttings are often placed in containers or nursery pots where environmental conditons such as soil moisture and light exposure can be controlled more effectively during the early stages of plant development.

Once the callused cuttings are ready, they are planted vertically in well-drained soil or substrate mixtures that allow adequate aeration and prevent waterlogging around the base of the stem (GrowVeg, 2024). Proper drainage is important because dragon fruit stems are highly susceptible to rot when exposed to excessive moisture in poorly aerated soils (Grow Well Guides, 2026). In nursery conditions, young plants are commonly supported with small stakes or poles to help maintain upright growth while roots develop and new shoots begin to emerge, a practice that also prepares the plant for later trellis-based cultivation systems used in commercial production (Hesp, 2026). This early structural support and controlled growth environment significantly improve plant survival and uniformity before transplantation to the field (Anushi et al., 2022).

Through these nursery techniques, growers are able to produce large numbers of genetically consistent plants that establish rapidly once planted in permanent cultivation areas.

Figure 22

Dragon Fruit Stem Cuttings Established in Nursery Containers

Note. Photo used from Dragon fruit Obsession, (Hesp, 2026). The image shows several *Selenicereus undatus* stem cuttings planted in nursery pots and supported with stakes. This setup illustrates a common nursery propagation technique in which cuttings are placed in well-drained substrate and maintained under controlled conditions until roots and new shoots develop. As said, this approach improves establishment success and allows growers to produce uniform plants before transferring them to field cultivation systems (Kakade et al., 2021) (GrowVeg, 2024).

4.2 Cultivation and Production

4.2.1 Growth Stages and Fruiting

The productive cycle of *Selenicereus undatus* involves a sequence of vegetative and reproductive stages that determine the timing and efficiency of fruit production under cultivation systems (Kabir et al., 2024). After propagation and establishment, plants initially focus on vegetative expansion, producing elongated triangular stems that function both as photosynthetic structures and as the framework that will later support reproductive organs (Kabir et al., 2024). As describes previously in Chapter 3, when discussing life cycle and phenology, environmental factors such as temperature, light availability, and water supply influence the transition between vegetative and reproductive phases. In cultivation systems, however, these transitions are also shaped by management practices such as pruning, structural support, and nutrient management, which aim to encourage strong vegetative architecture before flowering begins (Organic Crop Protectants, 2025). This early developmental phase is particularly important because the number and distribution of mature stems directly influence the plant's future flowering potential and fruit yield (Budiarto et al., 2025).

Once plants reach a sufficient level of maturity, reproductive development begins with the formation of flower buds that eventually produce the large nocturnal flowers characteristic of dragon fruit species (Grow Well Guides, 2026). This shift from vegetative growth to reproductive activity typically occurs when environmental conditons are favorable, particularly during periods of warm temperatures and adequate light exposure (Bozhurin, 2024). Following successful pollination, fruit formation proceeds rapidly as the ovary begins to enlarge and differentiate into the developing fruit structure (Grow Well Guides, 2026). Studies have shown that the developmental progression from early fruit formation to full ripeness occurs within a relatively short time frame, which contributes to the crop's potential for multiple harvest cycles within a single growing season (Cho & Ding, 2024). During this period, physiological processes such as cell expansion, pigment accumulation, and sugar synthesis gradually transform the fruit's internal and external characteristics, ultimately producing the distinctive coloration and pulp texture associated with mature dragon fruit (Shameena, 2024).

The visual progression of fruit maturation can be observed across successive developmental stages, where young fruits initially display green external tissues before gradually acquiring the intense pink coloration that indicates ripeness (Grynets, 2023). In **Figure 23**, these changes can be seen across several days after fruit set, illustrating how the fruit's morphology and internal pulp composition evolve as maturation progresses. This sequence reflects the rapid physiological transformation that occurs during fruit development and highlights why careful monitoring of fruit stages is important in commercial production system. By understanding the timing of these developmental transitions, growers can better coordinate irrigation, nutrient management, and harvest scheduling in order to maintain consistent fruit quality and maximize yield within a cultivation cycle (Cho & Ding, 2024).

Figure 23

Sequential Stages of Dragon Fruit Development Following Fruit Set

Note. Figure acquired from Multidisciplinary Digital Publishing Institute, (Shameena, 2024). It depicts the progressive development of *Selenicereus undatus* fruits across several days after fertilization, including changes in peel coloration, internal pulp pigmentation, and seed visibility. Early stages are characterized by green external tissues and underdeveloped pulp, while later stages show the characteristic pink peel and fully developed pulp associated with ripe dragon fruit. These transformations reflect the physiological processes of cell expansion, pigment formation, and sugar accumulation that occur during the fruiting stage of the plant's growth cycle (Shameena, 2024).

4.2.2 Cultural Practices: Fertilizing, Pruning, and Crop Management

Succesful cultivation of *Selenicereus undatus* depends not only on propagation techniques but also on a series of cultural practices that maintain plant vigor and optimize fruit production. Among the most important of these practices is fertilization, which ensures that plants receive sufficient nutrients to sustain both vegetative growth and fruit development (Schiffermuller, 2024). Dragon fruit plants typically require balanced nutrient inputs containing nitrogen (N), phosphorus (P), and potassium (K), elements that support stem growth, root development, and fruit formation respectively (Schiffermuller, 2024). Nitrogen promotes the production of new stems and vegetative tissue, phosphorus supports root establishment and energy transfer within plant cells, and potassium contributes to fruit quality by regulating water balance and carbohydrate transport (Karunakaran et al., 2025). Because dragon fruit is a perennial cactus with repeated flowering cycles, meaning its a drought-tolerant plant that lives for many years, nutrient supply must be maintained throughout the year through periodic fertilizer applications rather than a single seasonal treatment (Schiffermuller, 2024). This nutrient management strategy complements the propagation and establishment processes described earlier in this chapter by ensuring that newly established plants can sustain continuous growth and reproductive activity.

Pruning represents another essential management practice in dragon fruit cultivation because it regulates plant structure and encourages productive growth. As previously noted in **Section 4.2.1**, the plant produces elongated climbing stems that can become dense and overcrowded if left unmanaged. Pruning involves selectively removing older or excessive stems to improve light penetration, air circulation, and overall plant architecture (Mayer, 2023). Improved air circulation reduces humidity around plant tissues, which lowers the risk of fungal infections and other diseases that may affect cactus crops (Karunakaran et al., 2025). At the same time, removing weak or damaged stems allows the plant to redirect resources toward healthier branches that are more likely to produce flowers and fruit (Mayer, 2023). In commercial orchards, pruning is often coordinated with trellising systems, which are support structures that guide stem growth and maintain the plant in a manageable canopy shape suitable for harvesting and maintainance operations (Mayer, 2023).

Crop management practices integrate fertilization and pruning with other cultivation techniques that maintain optimal growing conditions throughout the production cycle. These practices include irrigation scheduling, weed control, and monitoring plant health to ensure that environmental conditions remain favorable for growth and fruiting (Mayer, 2023). Irrigation is particularly important because dragon fruit plants, despite being cacti, require consistent moisture during active growth and fruit development stages (Karunakaran et al., 2025). However, excessive water ca lead to root rot and other physiological stress conditions, making well-drained soil and controlled irrigation essential components of effective crop management (Schiffermuller, 2024). By coordinating nutrient supply, plant structure management, and environmental monitoring, growers are able to maintain stable production systems that support repeated flowering cycles and consistent fruit yields over multiple growing seasons (Schiffermuller, 2024). The practices involved in the process of dragon fruit cultivation are summarized in **Table 7**.

Table 7

Key Cultural Practices in the Cultivation of Selenicereus undatus

CULTURAL PRACTICCE	**DESCRIPTION**	**PURPOSE IN CULTIVATION**
Fertilization	Periodic application of nutrients such as nitrogen, phosphorus, and potassium to soil or substrate.	Supports vegetative growth, root development, and fruit formation.
Pruning	Selective removal of older, damaged, or excessive stems.	Improves plant structure, airflow, and allocation of resources to productive stems.
Trellising	Use of vertical support structures to guide climbing stems.	Maintains plant stability and facilitates harvesting and maintenance.
Irrigation Management	Controlled water supply adjusted to growth and fruiting stages.	Ensures adequate moisture while preventing waterlogging and root diseases.

Note. Table made based on information from the National Library of Medicine (Karunakaran et al., 2025). It summarizes the principal cultural practices used in dragon fruit cultivation and their functional role in maintaining plant productivity. These management techniques support nutrient availability, plant architecture, and environmental balance, all of which are necessary for sustaining repeated growth and fruiting cycles in *Selenicereus undatus* cultivation systems (Schiffermuller, 2024).

4.2.3 Harvesting and Post-Production Management

The final stage of the cultivation cycle involves harvesting the fruit and applying post production practices that maintain quality during storage and distribution (Shameena, 2024). Dragon fruit is typically harvested when the peel changes from green to its characteristic bright pink or red coloration, indicating that the fruit has reached physiological maturity (Schiffermuller, 2024). At this age, the pulp has completed most of its sugar accumulation and the fruit has developed the flavor and texture expected for commercial markets (Mitra, 2024). Harvesting is generally performed manually using pruning shears or knives to detach the fruit from the plant while leaving a short portion of the stem attached (Mitra, 2024). This method reduces mechanical damage to the fruit and prevents tearing of the plant tissue, which could otherwise affect subsequent flowering cycles (Mitra, 2024). In many production systems, harvesting is carried out several times during the growing season because fruits within the same plant often reach maturity at different times (Mayer, 2023).

After harvest, careful handling becomes essential to preserve fruit quality and extend shelf life. Dragon fruit has a relatively delicate peel that can be easily bruised if fruits are dropped or compressed during handling (Mitra, 2024). For this reason, fruits are usually sorted, cleaned, and placed in protective packaging shortly after harvest to prevent mechanical damage during transportation (Tonetto de Freitas et al., 2011). One common post-harvest practice involves placing fruits in partitioned boxes or containers with padding materials that reduce friction between individual fruits, as illustrated in **Figure 24** (Mitra, 2024). Temperature and humidity conditions must also be controlled during storage because excessive heat accelerates respiration and water loss, which can lead to shriveling and deterioration of the fruit's appearance and texture (Mitra, 2024). Maintaining moderate storage temperatures and adequate ventilation helps slow these physiological processes and prolong the fruit's marketable life (Karunakaran et al., 2025).

Postproduction management also includes grading and selection procedures that classify fruits according to size, color uniformity, and absence of defects (Organic Crop Protectants, 2025). This grading process allows producers to separate fruits intended for fresh consumption from those that may be used for processing or local markets (Tonetto de Freitas et al., 2011). By combining careful harvesting techniques with appropriate postharvest handling practices, growers can preserve fruit quality while reducing losses during transportation and storage (Tonetto de Freitas et al., 2011). These management steps are therefore an essential extension of the cultivation practices described earlier in this chapter, ensuring that the fruit produced through proper propagation and crop management ultimately reaches consumers in optimal condition.

Figure 24

Dragon Fruits Arranged in Protective Packaging after Harvest

Note. Image amended from Postharvest Research and Extension Center, (Tonetto de Freitas et al., 2011). It shows harvested dragon fruits arranged in compartmentalized packaging that separates individual fruits to reduce mechanical damage during transport and storage (Mitra, 2024).

4.3 Pest and Disease Management

4.3.1 Major Pests and Diseases and Their Control

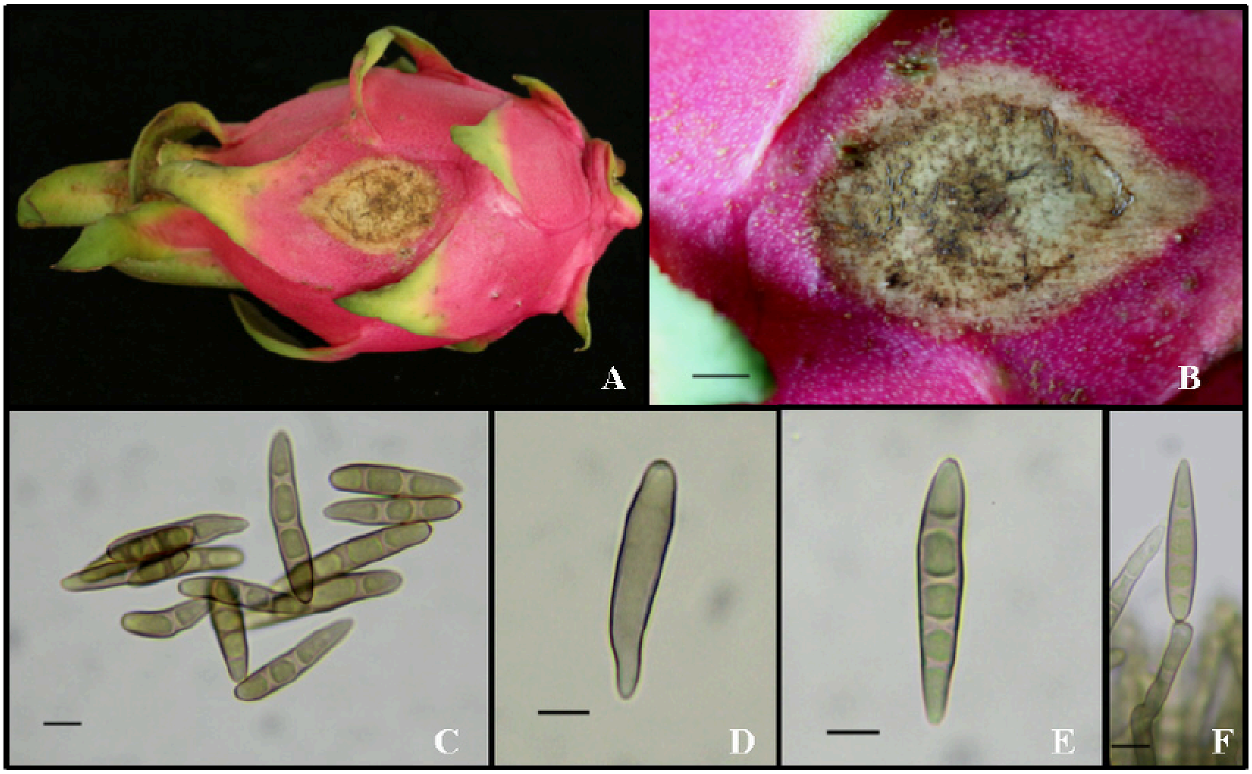
Like many fruit crops, Selenicerus undatus can be affected by a range of pests and plant diseases that interfere with plant health and reduce fruit production (Schiffermuller, 2023). Pests are organisms that damage crops by feeding on plant tissues or transmitting pathogens, while plant diseases are typically caused by microorganisms such as fungi, bacteria, or viruses, that disrupt normal plant functions (Grant, 2021). Among the most frequently reported pests in dragon fruit cultivation are aphids, mealybugs, and scale insects, which feed on plant sap by inserting specialized mouthparts into stem tissues (Grant, 2021). Sap feeding weakens the plant by removing nutrients and can also lead to the accumulation of sticky residues known as honeydew, a sugary substance excreted by insects that promotes the growth of sooty mold fungi on plant surfaces (Grant, 2021). In addition to insects, certain pests such as mites and fruit flies may damage developing fruits by puncturing the peel, which can reduce fruit quality and increase susceptibility to secondary infections (Schiffermuller, 2023).

Plant diseases in dragon fruit cultivation are often associated with fungal or bacterial pathogens that infect stems, roots, or fruits under favorable environmental conditions (Chhetri, 2024). One commonly resported disease is stem rot, which occurs when fungal pathogens invade damaged or weakened stem tissues, causing softening, discolorations, and eventual decay of the plant structure (Chhetri, 2024). Another issue observed in some cultivation systems is anthracnose, a fungal disease that produces dark lesions on stems and fruits and can spread rapidly in humid conditions if not properly managed (Grant, 2021). Because dragon fruit stems contain high moisture content, excessive humidity and poor air circulation can create conditions that favor the development of these pathogens (Chhetri, 2024). The visual symptoms associated with some of these infections, such as lesions or tissue breakdown on stems and fruits, are illustrated in **Figure 25**.

Effective pest and disease management strategies combine monitoring, preventive practices, and targeted control measures (Chhetri, 2024). Regular inspection of plants allows growers to detect early signs of infestation or infection before damaged becomes widespread (Schiffermuller, 2023). Cultural practices such as pruning, which was previously discussed in **Section 4.2.2**, help improve airflow and reduce humidity levels around plant tissues, thereby lowering the risk of fungal development (Chhetri, 2024). In some cases, biological control methods or carefully selected pesticides may be used to reduce pest populations when infestations become severe (Grant, 2021). By integrating these approaches with the cultivation and crop management practices described earlier in this chapter, producers can maintain healthier plants and protect the productivity of dragon fruit orchards over multiple growing seasons (Schiffermuller, 2023).

Figure 25

Symptoms of Pest and Disease Damage in Dragon Fruit Plants



Note. Photo amended from ResearchGate (Oeurn, 2015). The figure shows visible symptoms that may occur in dragon fruit plants when affected by pests or pathogens, like the lesions on stems or fruits and tissue deterioration caused by fungal or bacterial infections. Such symptoms are commonly associated with diseases like anthracnose or stem rot, which develop under humid conditions and can spread rapidly if plants are not properly monitored and managed. Early detection of these signs allows growers to implement control strategies and prevent further damage to the crop (Chhetri, 2024).

5.0 Importance, Markets and Uses

5.1 Global Importance and Production

5.1.1 Major Producing Countries and Production Volumes

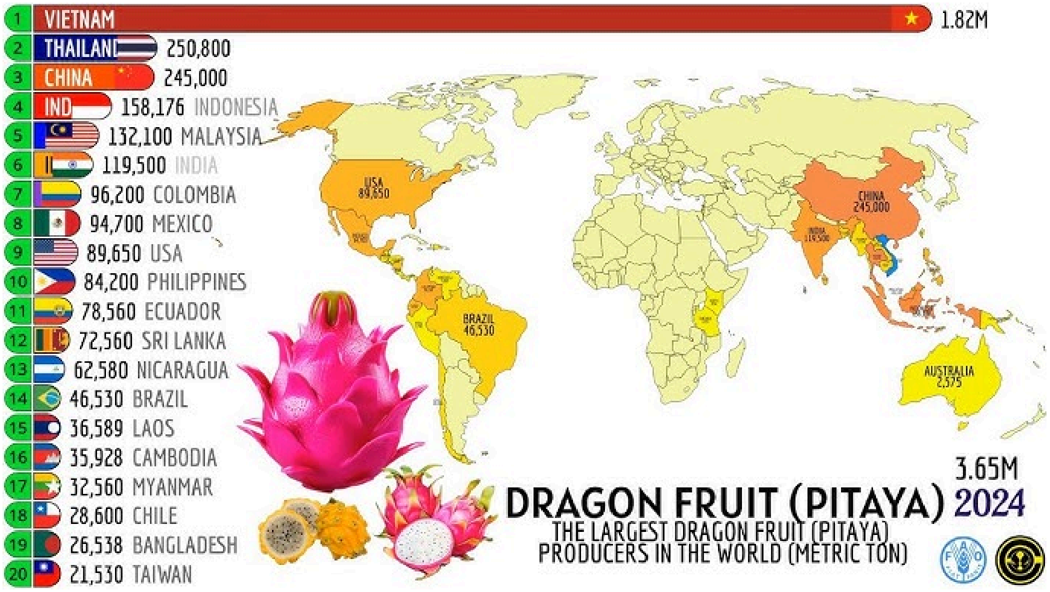
Dragon fruit production is highly concentrated in Asia, where favorable climatic conditions and early adoption of commercial cultivation systems have allowed several countries to dominate global output (Chen & Paull, 2018). Among these, Vietnam stand as the leading producer, contributing the largest share of global production due to its extensive plantation systems and export-oriented industry (Kaur, 2025). Large production areas, particularly in southern Vietnam, support continuous harvesting cycles, which significantly increase annual yield and stabilize supply for international markets (TradeImeX, 2025). This high production capacity has positioned the country as a central supplier in the global dragon fruit trade.

China has also emerged as a mayor producer in recent years, driven by rapid expansion of cultivation areas and strong domestic demand (Kaur, 2025). In addition, countries such as Thailand, Indonesia, and Malaysia contribute substantially to total production, with cultivation systems that range from smallholder farms to larger commercial operations (Mitra, 2024). These countries benefit from tropical climates that allow multiple harvest cycles per year, increasing overall production volumes and supporting regional market growth (Chen & Paull, 2018). As a result, Asia, collectively accounts for the majority of global dragon fruit production.

Outside of Asia, production is more limited but continues to expand, particularly in Latin America. Countries such as Mexico and Nicaragua have established commercial production systems, while others like Colombia are increasing cultivation as part of agricultural diversification strategies (TradeImeX, 2025). Although these regions currently produce lower volumes compared to Asian countries, their contribution is becoming more relevant in supplying niche markets and supporting export growth (Mitra, 2024). Overall, global production volumes continue to rise as cultivation spreads geographically, as shown in **Figure 26**, reflecting both increasing demand and the crop's adaptability to different agricultural systems (Chen & Paull, 2018).

Figure 26

Global Distribution of Dragon Fruit Production by Country (2024)



Note. Image taken from CityGlobe Tour (CityGlobe Tour, 2025). The figure illustrates the global distribution of dragon fruit production, highlighting the leading producing countries and their approximate output in metric tons. Vietnam is shown as the dominant producer, followed by Thailand, China, and Indonesia, showing the concentration of production in Asia. Additional producers in Latin America, are also represented. This distribution supports the discussion of regional dominance and the expanding global production of dragon fruit (Mitra, 2024).

5.1.2 Economic Value of Global Production

As introduced in **Section 5.1.1,** dragon fruit production is geographically concentrated in a few dominant regions, particularly in Asia, where large-scale cultivation systems support high output levels (Rebecca, 2025). This concentration of production has directly contributed to the crop's increasing economic value, as dragon fruit has transitioned from a niche tropical fruit into a high-value commodity in international markets (Rebecca, 2025). The global dragon fruit market has experienced steady growth in recent years, driven by rising consumer demand, expanding export networks, and the fruit's perceived health benefits (Reddy, 2026). This growth has elevated the economic importante od the crop beyond primary production, positioning it as a significant contributor to agricultural trade in producing countries (Reddy, 2026).

In terms of market value, the global dragon fruit industry is estimated to be worth several billions of dollars, with projections indicating continued expansion due to increasing demand in regions such as North America and Europe (Rebecca, 2025). This economic value is closely linked to the fruit's classification as a premium product, often sold at higher prices compared to other tropical fruits due to its visual appeal, nutritional profile, and limited supply in non-producing regions (Silor et al., 2024). Additionally, the export-oriented nature of major producing countries, particularly Vietnam as mentioned in **Section 5.1.1**, allows them to capture a significant share of this value through international trade (TradeImeX, 2025). The combination of high demand and limited production areas contributes to price stability and profitability within the market.

The economic significance of dragon fruit production is also reflected in its role in supporting rural economies and agricultural diversification. In many producing countries, the crop provides farmers with an alternative source of income that is often more profitable than traditional crops due to its relatively high market price and increasing global demand (Silor et al., 2024). Furthermore, improvements in cultivation techniques and supply chain infrastructure have allowed producers to increase yields and access new markets, further enhancing the overall economic impact of the crop (Reddy, 2026). As global production continues to expand, the economic impact of dragon fruit is expected to grow, reinforcing its position as an important agricultural commodity in both regional and international contexts. These combined factors highlight the growing economic importance of dragon fruit production at a global scale, which is further summarized in **Table 8.**

Table 8

Estimated Global Economic Value and Market Characteristics of Dragon Fruit Production

ASPECT	DESCRIPTION	ECONOMIC IMPLICATION
Global market value.	Multi-billion dollar industry with continuous growth.	Reflects increasing global demand and market expansion.
Demand trends.	Rising demand in North America and Europe.	Expands export opportunities for producing countries.
Product classification.	Considered a premium fruit in international markets.	Allows higher pricing compared to conventional fruits.
Export orientation.	Strong reliance on exports from major producers.	Increases foreign revenue and trade significance.
Farmer income.	Provides higher returns than many traditional crops.	Supports rural economic development.

Note. Table constructed based on Global Dragon Fruit Market (Rebecca, 2025). It summarizes key economic studies on *Selenicereus undatus* production, including market value, demand trends, and implications for producers and international trade.

5.2 Regional and National Economic Importance

5.2.1 Role in Latin American Agriculture

In Latin America, dragon fruit cultivation has gained importance as part of broader agricultural diversification strategies, particularly in tropical and subtropical regions where environmental conditions support its growth (Ibrahim, 2018). As previously discussed in **Chapter 2,** the species is well adapted to warm climated with well-drained soils, which has facilitated its expansion across multiple Latin American countries (Belbase & Bhaskar, 2025). This adaptability has allowed farmers to incorporate dragon fruit into existing agricultural systems, often replacing or complementing traditional crops with lower economic returns (Belbase & Bhaskar, 2025). In countries such as the Dominican Republic, the promotion of dragon fruit cultivation has been encouraged as a way to increase agricultural productivity and generate new income opportunities in for rural communities (Ibrahim, 2018). The crop's relatively high market value and growing international demand have made it an attractive option for farmers seeking to improve economic stability through crop diversification (Ibrahim, 2018).

Beyond its economic potential, dragon fruit also plays a role in supporting more sustainable agricultural practices in the region. The plant's cactus physiology, which allows it to store water and tolerate periods of drought, reduces its dependence on constant irrigation compared to more water-intensive crops (San Diego Zoo, 2022). This characteristic is particularly relevant in areas facing variable rainfall or limited water availability, where efficient resource use becomes essential for long-term agricultural viability (San Diego Zoo, 2022). Additionally, the expansion of dragon fruit cultivation has contributed to the development of local and regional markets, strengthening value chains and encouraging investment in agricultural infrastructure (Belbase &

Bhaskar, 2025). As a result, the crop not only provides direct economic benefits to producers but also supports broader agricultural development by promoting diversification, sustainability, and market integration within Latin American farming systems (Ibrahim, 2018).

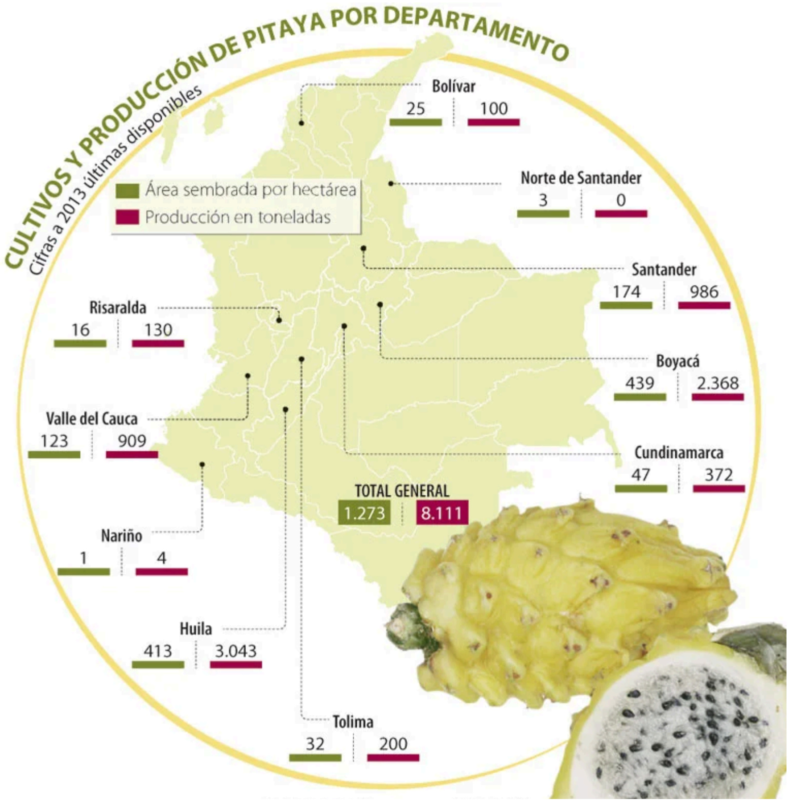
5.2.2 Production and Market Development in Colombia

In Colombia, dragon fruit production has developed as a specialized agricultural sector with increased national and international relevance. As part of the broader expansion of dragon fruit cultivation in Latin America discussed in **Section 5.2.1,** Colombia has taken advantage of its diverse climatic regions to support production across multiple departments (Ortiz & Takahashi, 2020). The crop is primarily cultivated in areas such as Huila, Valle del Cauca, Boyacá, and Santander, where environmental conditions such as temperature, altitude, and soil characteristics favor both vegetative growth and fruit development (Ortiz & Takahashi, 2020). Among these regions, Huila stands out as one of the leading producers, contributing a significant portion of national output due to its established cultivation systems and favorable agroecological conditions (Tridge, 2023). This regional distribution of production highlights how dragon fruit cultivation in Colombia is not concentrated in a single area, but rather dispersed across multiple productive zones, as shown in **Figure 27**.

The development of the dragon fruit market in Colombia has been closely linked to both domestic consumption and export opportunities (Tridge, 2023). While a portion of production is sold within national markets, the crop is largely oriented toward international trade, with exports directed to regions such as Europe and North America where demand for exotic fruits continues to grow (Tridge, 2023). This export focus has encouraged improvements in production practices, quality control, and supply chain organization in order to meet international standards (Reed, 2025). In addition, the emergence of value-added products such as dragon fruit powder has contributed to market diversification, allowing producers to extend the economic value of the crop beyond fresh fruit sales (Reed, 2025). These developments reflect a transition from traditional agricultural production toward a more integrated market system, where both raw and processed forms of dragon fruit contribute to Colombia's agricultural economy (Ortiz & Takahashi, 2020).

Figure 27

Distribution of Dragon Fruit Production and Cultivated Area in Colombia by Department



Note. Image amended from Agronegocios (Martínez, 2015). It shows the distribution of dragon fruit cultivation across different Colombian departments, including both planted area (in hectares) and production levels (in tons). This spatial distribution illustrates how production is regionally diversified rather than concentrated in a single area, supporting the discussion of Colombia's decentralized cultivation system and its role in national and export markets (Ortiz & Takahashi, 2020).

5.3 Market Structure and Trade

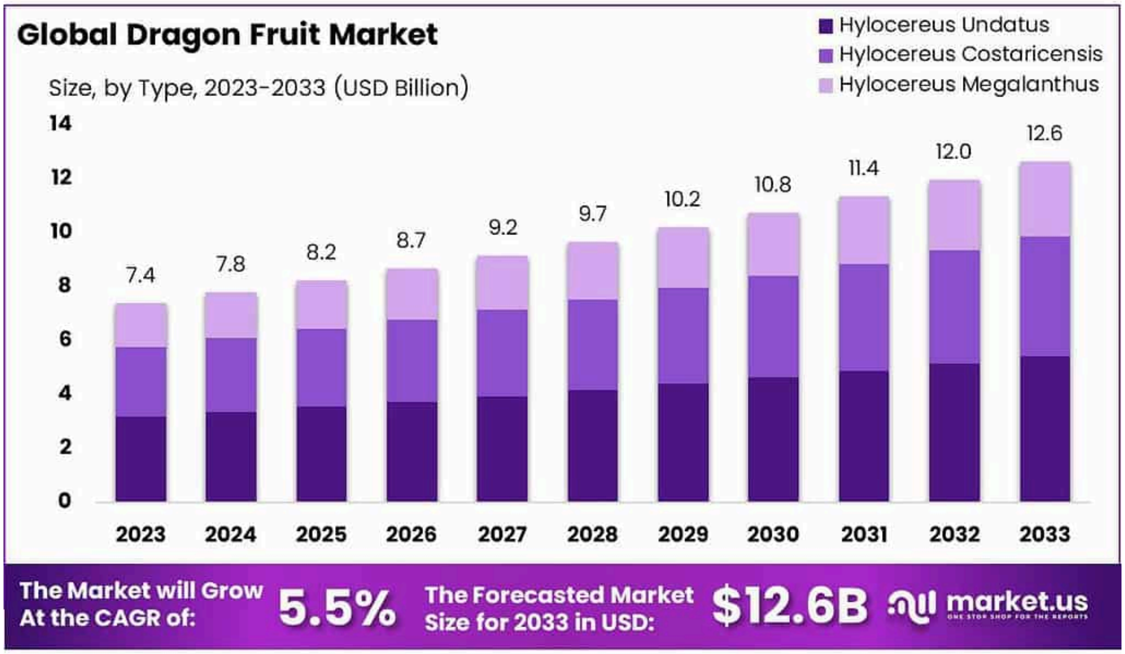
5.3.1 International Trade and Export Markets

The international trade of dragon fruit has expanded significantly as global demand for exotic and nutritionally valued fruits continues to increase. As mentioned, the crop has transitioned into a high-value commodity, and this shift is strongly reflected in its export dynamics, where a small number of countries dominate global trade (Rebecca, 2025). Vietnam remains the leading exporter of *Selenicereus undatus* worldwide, supplying a large proportion of international markets due to its high production capacity and well-established export infrastructure (Cypher, 2025). Other countries such as Thailand, Ecuador, and Israel also participate in export markets, although at smaller scales, contributing to a diversified but still concentrated global supply network (Cypher, 2025). These exporting countries primarily target markets in North America, Europe and parts of Asia, where consumer demand for tropical fruits has grown steadily over recent years (Schiffermuller, 2025).

The development of international trade has also been influenced by improvements in logistics, storage, and postharvest handling, which allow dragon fruit to be transported over long distances while maintaining quality (Schiffermuller, 2025). As discussed in **Chapter 4**, postharvest practices such as careful packaging and temperature control are essential for preserving the fruit during export, and these practices directly support participation in global markets (Mitra, 2024). Over time, the expansion of trade networks has allowed dragon fruit to move beyond regional markets and become a globally tarded product, with increasing volumes entering international supply chains (Schiffermuller, 2025). This growth is reflected in the continuous rise of the global market value, which is projected to increase steadily over the next decade, as shown in **Figure 28**.

Figure 28

Projected Growth of the Global Dragon Fruit Market by Type (2023-2033)



Note. Graph from Dragon Fruit Market (Dragon Fruit Market, 2024). It illustrates the projected expansion of the global dragon fruit market from 2023-2033, showing an increase in total markey size from approximately 7.4 billion USD to around 12.6 billion USD. It also distinguishes between different species, including Hylocereus undatus, Hylocereus costaricensis, and Hylocereus megalanthus, highlighting their respective contributions to overall market growth. This trend reflects the increasing demand for dragon fruit in international marklets and supports the discussion of expanding export networks and global trade dynamics (Reddy, 2026).

5.3.2 Distribution and Market Channels

The distribution of dragon fruit from production areas to final consumers involves a series of interconnected market channels that vary depending on whether the fruit is destined for domestic consumption or export markets (Ummer, 2025). After harvest, dragon fruit typically enters local supply chains through collection centers or intermediaries, where it is sorted and prepared for sale in wholesale markets (Agricultural Marketing Resource Center, 2024). From there, the fruit is distributed to retailers such as supermarkets, specialty fruit stores, and local markets, where it reaches consumers in fresh form (Agricultural Marketing Resource Center, 2024). In producing countries, this domestic distribution system allows farmers to sell part of their production locally, supporting national food markets while reducing dependence on exports (Ummer, 2025). These internal market channels are particularly important in regions where consumption of dragon fruit has increased alongside production.

In contrast, export-oriented distribution channels involve more complex supply chains that include exporters, distributors, and international retailers (Ummer, 2025). As mentioned in **Section 5.3.1**, countries that participate in global trade must meet specific quality and handling standards, which requires additional steps such as grading, packaging, and cold chain transportation before the fruit is shipped abroad (Ummer, 2025). Once exported, dragon fruit is distributed through importers and wholesale distributors in destination countries, eventually reaching supermarkets and food service industries (Agricultural Marketing Resource Center, 2024). The development of these structured market channels has been essential for integrating dragon fruit into global markets, as it ensures consistent quality and availability across different regions (Ummer, 2025). Overall, the coexistence of domestic and international distribution systems allows dragon fruit to function as both a locally consumed product and a globally traded commodity, depending on the market demand and production scale (Agricultural Marketing Resource Center, 2024).

5.4 Products and Commercial Uses

5.4.1 Fresh Fruit Consumption

Fresh consumption represents the primary form in which dragon fruit is marketed and consumed worldwide, and it plays a central role in driving demand within both domestic and international markets (Jones et al., 2023). The expansion of production and trade has allowed the fruit to become more widely available, particularly in regions where it is not traditionally grown (Thomson, 2021). In its fresh form, dragon fruit is typically consumed raw, either cut into slices or scooped directly from the peel, which makes it a convenient and ready-to-eat product for consumers (Jones et al., 2023). Its mild sweetness, combined with a soft texture and visually distinctive appearance, has contributed to its popularity in fresh fruit markets, especially in supermarkets and specialty stores (Thomson, 2021). This ease of consumption and appealing presentation have positioned dragon fruit as a premium fresh fruit in many international markets (Thomson, 2021).

In addition to its sensory characteristics, fresh dragon fruit consumption is strongly associated with its nutritional and perceived health benefits (Thomson, 2021). The fruit is low in calories but contains important nutrients such as vitamin C, fiber, and antioxidants, which contribute to its reputation as a healthy dietary option (Jones et al., 2023). These nutritional properties have increased consumer interest, particularly among health-conscious populations, further supporting demand in fresh fruit markets (Jones et al., 2023). Furthermore, fresh dragon fruit is often incorporated into a variety of culinary applications, including fruit salads, smoothies, and desserts, which expands its versatility beyond simple consumption (Thomson, 2021). As a result, the fresh fruit segment remains the most important market channel for dragon fruit, forming the foundation for its global commercialization and influencing both production and distribution patterns discussed in earlier sections.

5.4.2 Processed and Value-Added Products

Beyond fresh consumption, dragon fruit has gained importance in processed and value-added markets, where its characteristics allow it to be transformed into a wide range of commercial products (Ummer, 2025). As introduced in **Section 5.4.1**, the fruit's color appealing color, texture, and flavor make it attractive in its natural form, but these same properties also make it highly suitable for processing into products such as juices, jams, and beverages (Wongsa & Mitra, 2024, 31-46). Processing extends the shelf life of the fruit, which is particularly important given its relatively delicate structure and susceptibility to postharvest deterioration (Lokesh et al., 2023, 396-410). This allows producers to reduce losses while also reaching markets that are geographically distant from production areas (Dam, 2022). As a result, value-added processing has become an important strategy for increasing the overall economic value of dragon fruit production (Dam, 2022).

In addition to traditional processed foods, dragon fruit is increasingly used in more specialized products, including powders, natural colorants, and nutraceutical formulations. The fruit's high content of pigments and bioactive compounds has encouraged its use as a natural food coloring agent and as an ingredient in functional foods and health-related products (Lokesh et al., 2023, 396-410). For example, dragon fruit powder is commonly used in smoothies, supplements, and processed food products due to its concentrated nutritional properties and extended shelf life (Yang et al., 2025). Similarly, small-scale processing initiatives, such as homemade jams, syrups, and dried fruit, have been promoted as a way to add value at the local level and support rural economies (Yang et al., 2025). These diverse applications demonstrate how dragon fruit processing contributes to market diversification and enhances the crop's commercial potential, as summarized in **Table 9.**

Table 9

Common Processed and Value-Added Products Derived from Dragon Fruit

PRODUCT TYPE	DESCRIPTION	PURPOSE / MARKET USE
Juice and beverages	Extracted liquid use in drinks and flavored products.	Expands consumer market and increases product versatility.
Jams and preserves	Cooked fruit products with added sugar.	Extends shelf life and allows storage and transport.
Dried fruit	Dehydrated slices or pieces.	Reduces perishability and creates snack products.
Powder	Processed and dehydrated fruit ground into powder.	Used in supplements, smoothies, and functional foods.
Natural colorants	Pigment extracts used in food and beverages.	Replaces synthetic dyes with natural alternatives.
Nutraceutical products	Extract-based products with health applications.	Targets health-conscious markets and adds economic value.

Note. Table constructed based on information from Futuristic Trends in Agriculture Engineering & Food Sciences (Lokesh et al., 2023, 396-410). It summarizes the main value-added products derived from dragon fruit and their corresponding uses in food, health, and industrial markets. These products demonstrate how processing increases shelf life, expands market opportunities, and enhances the overall economic value of the crop (Dam, 2022).

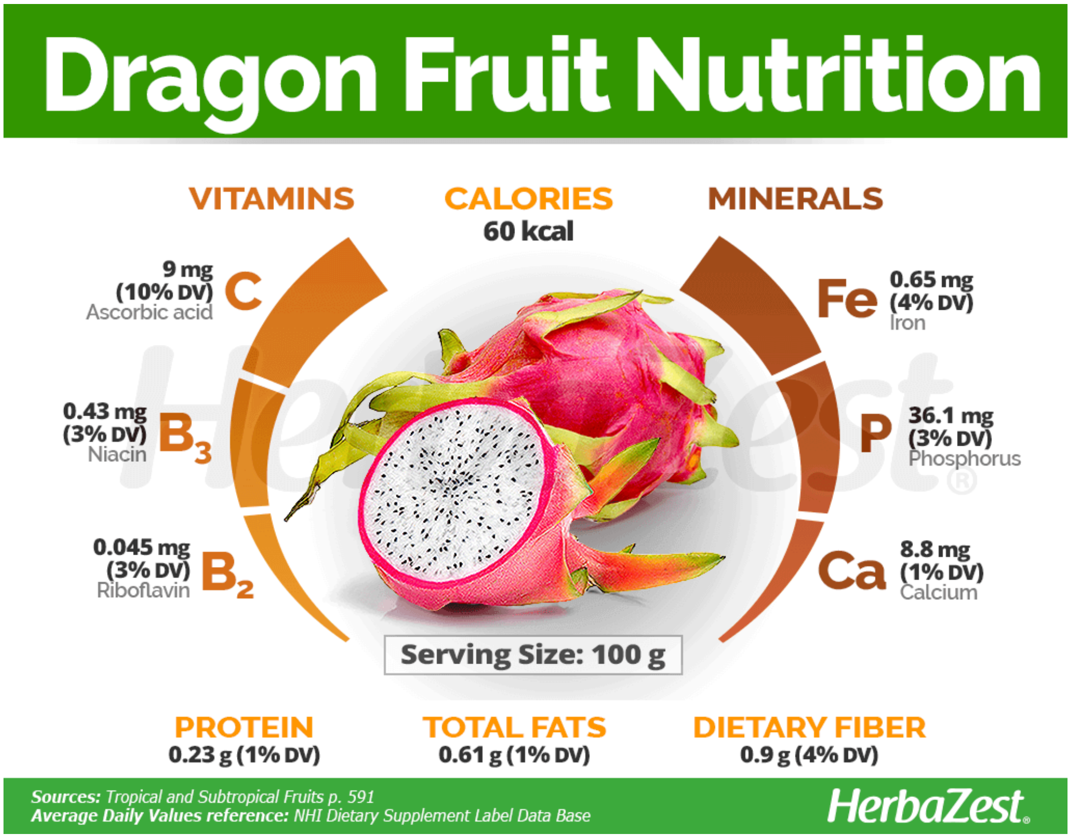
5.5 Nutritional and Functional Uses

Selenicereus undatus is widely recognized for its nutritional composition, which contributes to its growing demand in both fresh and processed markets (Naiker, 2024). Its popularity is partly driven by its health-related properties, which extend beyond basic nutrition. The fruit is characterized by a relatively low caloric content combined with the presence of essential nutrients such as vitamins, minerals, and dietary fiber (Naiker, 2024). For instance, dragon fruit contains vitamin C, which plays a role in immune function, as well as B vitamins that support metabolic processes (Apollo Hospitals, 2025). In addition, the fruit provides minerals such as iron, calcium, and phosphorus, which contribute to various physiological functions including oxygen transport and bone health (Apollo Hospitals, 2025). These nutritional components, summarized visually in **Figure 29**, explain why dragon fruit is frequently categorized as a functional food in modern diets.

Beyond its basic nutritional value, dragon fruit also exhibits functional properties due to the presence of bioactive compounds such as antioxidants and phytochemicals (Apollo Hospitals, 2025). These compounds help reduce oxidative stress in the body, which has been associated with a lower risk of chronic diseases (Naiker, 2024). The fruit's antioxidant capacity is particularly linked to its pigment compounds, which not only give it its characteristic color but also contribute to its potential health benefits (Naiker, 2024). Furthermore, the fiber content of dragon fruit supports digestive health by promoting regular bowel function and improving gut microbiota balance (Apollo Hospitals, 2025). These functional attributes have increased its use in health-oriented products, including supplements and nutraceuticals, as mentioned in **Section 5.4.2.** As a result, dragon fruit is not only consumed for its taste and appearance, but also for its contribution to overall health and well-being, reinforcing its importance in both nutritional and commerical contexts (Apollo Hospitals, 2025).

Figure 29

Nutritional Composition of Dragon Fruit per 100g Serving



Note. Photo from HerbaZest (Agatha, 2022). It illustrates the nutritional profile of dragon fruit, including its vitamin content (such as vitamin C and B vitamins), mineral composition (iron, phosphorus, and calcium), and macronutrient values such as calories, protein, fats, and dietary fiber. It highlights the fruit's low caloric value combined with essential nutrients, supporting its classification as a functional food. This nutritional composition explains the increasing demand for dragon fruit in health-conscious markets and its use in both fresh and processed forms (Naiker, 2024).

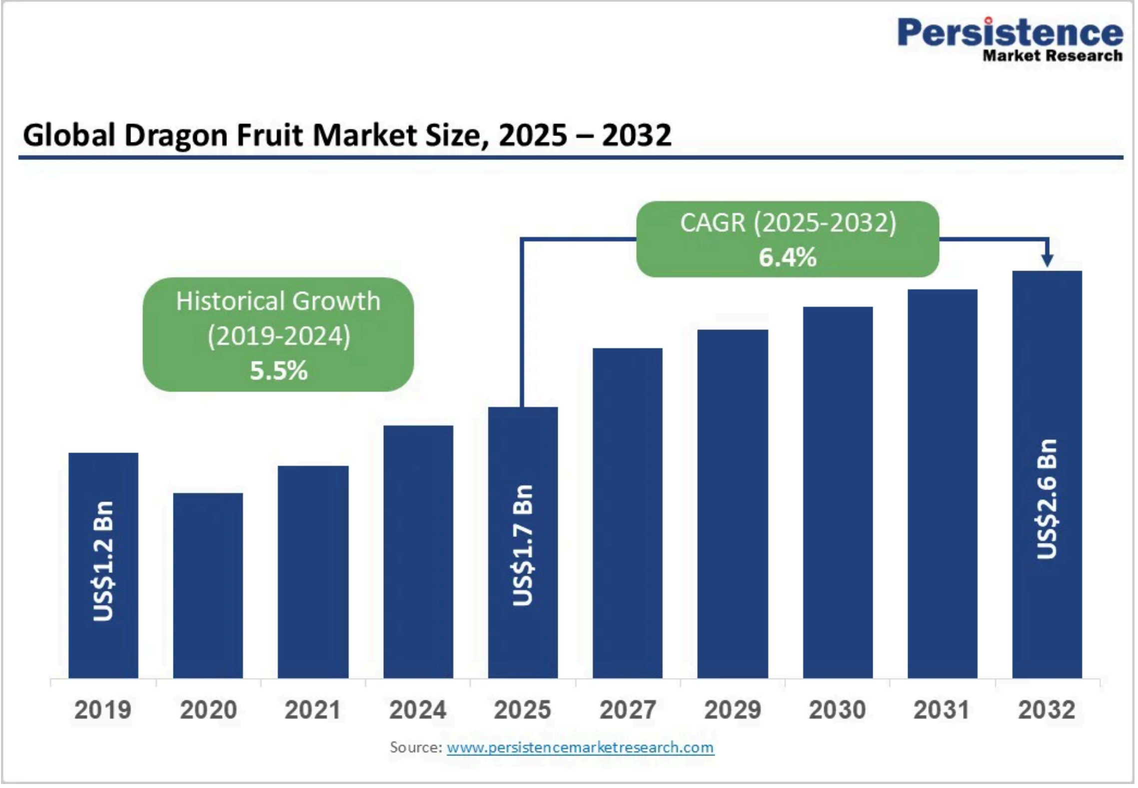
5.6 Future Market Trends and Economic Potential

The future of the dragon fruit industry is characterized by continued expansion in both production and market demand, driven by a combination of economic, nutritional, and agricultural factors (Market Report Analytics, 2026). As mentioned previously, the crop has already transitioned into a globally traded commodity, and current projections indicate that this trend will continue over the coming years (Market Report Analytics, 2026). Markets analyses suggest that the global dragon fruit industry will experience steady growth, supported by increasing consumer interest in exotic fruit and health-oriented products (Market Report Analytics, 2026). This demand is particularly strong in regions such as North America and Europe, where dragon fruit is still considered a premium product and consumption continues to rise (Javier, 2024, 195-200). As a result, the expansion of international trade networks and production systems is expected to further strengthen the economic importance of the crop at a global scale.

In addition to demand-driven growth, future market trends are also influenced by improvements in production techniques, supply chain efficiency, and product diversification (Javier, 2024, 195-200). Advances in cultivation practices, including better management strategies and technological integration, have allowed producers to increase yields and improve fruit quality, making dragon fruit more competitive in international markets (Javier, 2024, 195-200). At the same time, the development of value-added products continues to expand market opportunities by allowing producers to access new consumer segments and reduce postharvest losses (Market Report Analytics, 2026). These combined factors contribute to the long-term economic potential of the crop, positioning it as a sustainable and profitable option for both small-scale farmers and large agricultural enterprises. The projected growth of the global market, including increasing market value and compound annual growth rates, is illustrated in **Figure 30**.

Figure 30

Projected Growth of the Global Dragon Fruit Market (2025-2032)



Note. Figure amended from Persistence Market Research (Patil, 2025). It shows the projected expansion of the global dragon fruit market between 2025 and 2032, illustrating a steady increase in market size alongside a compound annual growth rate (CAGR) of approximately 6.4%. It also highlights earlier growth trends, including a historical growth rate of around 5.5% between 2019 and 2024. This upward trend reflects increasing global demand, expanding production systems, and the growing economic importance of dragon fruit in international markets, supporting its future potential as a high-value agricultural commodity (Market Report Analytics, 2026).

6.0 Concluding Analysis

The study of *Selenicereus undatus* demonstrates how a single plant species can integrate biological adaptation, agricultural efficiency, and economic relevance within a global context. As discussed in earlier chapters, dragon fruit is well adapted to tropical and subtropical environments, where factors such as temperature, soil conditions, and water availability support its growth and productivity (Chen & Paull, 2018) (Belbase & Bhaskar, 2025). Its cactus physiology, particularly its ability to store water and tolerate environmental variability, allows it to thrive in conditions that may limit other crops, reinforcing its role in sustainable agricultural systems (San Diego Zoo, 2022).

From a biological and production perspective, the species exhibits characteristics that make it highly efficient for cultivation. Its capacity for vegetative propagation enables rapid establishment and genetic consistency, which are essential for commercial systems (Kakade et al., 2021) (Anushi et al., 2022). Additionally, the relatively short period between pollination and fruit maturity allows for multiple harvest cycles within a single year, increasing overall productivity (Cho & Ding, 2024) (Shameena, 2024). These biological traits are directly supported by cultivation practices such as pruning, fertilization, and irrigation management, which optimize plant structure, nutrient availability, and fruit yield (Karunakaran et al., 2025) (Mayer, 2023).

At a broader scale, dragon fruit has evolved from a regionally cultivated crop into a globally traded agricultural commodity. Production remains concentrated in Asian countries such as Vietnam and China, but expansion into Latin America, including Colombia, highlights its adaptability and increasing economic importance (Kaur, 2025) (TradeImeX, 2025) (Ortiz & Takahashi, 2020) (Tridge, 2023). This growth is driven by rising global demand, supported by the fruit's classification as a high-value product with strong appeal in both fresh and processed markets (Jones et al., 2023) (Lokesh et al., 2023). Its nutritional properties and versatility in products such as juices, powders, and nutraceuticals further contribute to its commercial relevance and market expansion (Naiker, 2024) (Yang et al., 2025).

Looking forward, the future of dragon fruit production is characterized by continued growth, innovation, and global integration. Increasing consumer demand for health-oriented and exotic foods is expected to drive further expansion in both production and trade (Market Report Analytics, 2026) (Reddy, 2026). At the same time, improvements in cultivation techniques and supply chain systems will enhance productivity and reduce losses, strengthening the crop's role in modern agriculture (Belbase & Bhaskar, 2025). Overall, *Selenicereus undatus* represents a clear example of how biological adaptation, environmental conditions, and human management practices interact to shape a sustainable and economically significant agricultural system.

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