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Assessing the suitability of pitaya plant varieties for cultivation in the arid climate of Saudi Arabia

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A R T I C L E I N F O

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S undatus
S costaricensis
Fertilizers
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A B S T R A C T

Pitaya, sometimes called dragon fruit, is a tropical fruit crop that has become more well-known recently because of its distinct flavor and beneficial properties. However, it has only been cultivated in tropical and subtropical areas, and nothing is known about whether it can thrive in arid climates. This study considers various pitaya plant types' morphological, physiological, and agronomic aspects to assess their viability for cultivation in desert regions. This study investigated the growth and development of two cultivars of pitaya plants, *S. undatus* and *S. costaricensis*, in the Asir region of Saudi Arabia. Different fertilisation treatments were applied to determine the most effective approach for promoting growth and productivity. Results showed that the Klebak fertiliser, which contains marine algae rich in auxins and amino acids, was the most effective treatment for *S. undatus*. For *S. costaricensis*, the Klebak fertiliser was also effective, but treating tree leaves with volcanic stone was also beneficial. The volcanic stone helped to preserve moisture in the soil and promote good drainage, while the leaves provided important organic nutrients for growth. In addition, *S. costaricensis* was found to be more resistant and responsive to cultivation, likely due to its original habitat in the temperate climate of Mexico. These findings can help inform the cultivation of pitaya plants in similar climatic conditions. They may have implications for other areas seeking to promote the growth and productivity of this important crop.

1. Introduction

Pitaya fruit, commonly known as the dragon fruit or Pitaya, is an exotic fruit often found in Southeast Asia to South America. It is a member of the cactus family, specifically the Selenicereus genus. The fruit is round or oval, with a bright red or yellow skin and small, sweet-tasting pulp with black seeds. The Pitaya fruit, also known as pitaya or dragon fruit, is a member of the cactus family, specifically the genus Selenicereus, within the family Cactaceae. This exotic fruit has several species from southeastern Asia to South America. The pitaya plant is characterised by its beautiful white, fragrant flowers that only bloom at night, commonly called the "moonflower." The fruit of the pitaya plant is oblong or oval in shape, covered with a bright red or yellow peel, and has small scales that contain a white, juicy, sweet-tasting pulp with very small black seeds [1]. Originally hailing from Mexico, Central America, and South America, Pitaya

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is cultivated in East Asia and Southeast Asian countries such as Indonesia, Taiwan, Vietnam, Thailand, the Philippines, Sri Lanka, Malaysia, Cambodia, China, Sri Lanka, and Bangladesh. Europeans introduced it to Bangladesh and Saudi Arabia, where it is now grown [2]. The most famous pitaya plant is the red pitaya plant, native to Mexico, with white pulp and large, aromatic flowers (see Table 1, Figs. 3 and 11)

The fruit can weigh 1 kg or more and is oblong with red skin, translucent white pulp, and black seeds [3]. The Costa Rican pitaya plant, S. costaricensis, has thornier stems and bright red and purple fruits due to anthocyanin pigment. The yellow pitaya plant, S. megalanthus, is native to northern South America and is commercially produced for its golden fruits [4]. It has a yellow shell and white pulp, with oval-shaped fruits smaller than other varieties. The inner space is white, although it can be pink when hybridized. As demand for Pitaya grows, more exotic fruit varieties will likely be cultivated [5]. The pitaya plant is known for its adaptability to various soil types, including saline water and clay, sandy, rocky, and mountainous soils, making it an ideal crop for many countries. The pitaya plant is a climbing cactus perennial tree that can live for up to two decades in tropical lowlands. They thrive in moist and warm climates and nutrient-rich soil, making them suitable for tropical and subtropical regions. However, they are sensitive to cold weather and require specific growing conditions. After 13 years of research and experiments, Egypt has succeeded in cultivating this plant, opening up new opportunities for the country's agricultural sector [6].

The commercial production of Pitaya is on the rise, with a global production estimated at 21,00777 metric tons, with India contributing 1 % or 12,200 metric tons, ranking ninth in the world. Vietnam is currently the world's leading producer of Pitaya, accounting for 43 % of global production, followed by China, Indonesia, Thailand, and the Taiwanese state of Gujarat [7]. Vietnam's pitaya plant is known for its size, colour, and taste due to its warm climate and fertile land. The plant has been cultivated in Vietnam for over 100 years, and it is the only Southeast Asian country where it has been grown on a large commercial scale in large areas. The demand for the pitaya fruit is increasing globally, with more countries entering the market due to its high economic profitability and desirability. The fruit is considered the most expensive in the world, with a single fruit costing over $5 in some countries. It can reach up to 15 euros [6]. The pitaya plant's high value as a commodity and water-saving attributes are driving Saudi Arabia to increase the production of the plant. The Ministry of Environment, Water, and Agriculture and the National Center for Research and Development of Sustainable Agriculture organised a workshop on the potential of Pitaya in developing non-oil industries, highlighting its water conservation benefits and the potential for more countries to enter the global market [3,5].

Indonesia has intensively cultivated the pitaya plant for the last 15 years, with production centres in several provinces. The most common cultivar is the red. Similarly, the Kingdom of Saudi Arabia has recognised the potential of the pitaya plant and plans to increase its production as it is a high-value commodity that requires less water than other crops. The Ministry of Environment, Water, and Agriculture, in cooperation with the National Center for Research and Development of Sustainable Agriculture (Estidamah), hosted a workshop on promising crops in the Kingdom. Dr Rahma Nasser Jeris, a researcher at the ministry, presented a study highlighting the potential of Pitaya and its role in expanding non-oil industries as part of the Kingdom's Vision 2030 plan. The doctor emphasised that Pitaya is a tropical and subtropical plant that consumes less water than other crops, making it an attrActival option for farmers. Overall, pitaya cultivation is becoming increasingly important in the Arab world as countries recognise its economic potential and adaptability to various soil types. As research on this exotic fruit continues, we expect more countries to enter the global pitaya market [6,8].

The pitaya plant, also known as dragon fruit, comes in several varieties, each with unique characteristics. The most famous type is the red pitaya plant, also known as pitaya blanca, with white pulp, which is native to Mexico but now grown in many countries. This climbing cactus has large, aromatic flowers that bloom at night and are pollinated by bees the following morning. The resulting fruits can weigh 1 kg or more and are oblong, with red skin, translucent white pulp, and black seeds [6].

Another variety of pitaya plants is the Costa Rican pitaya plant, known as S. costaricensis. This variety is native to Costa Rica and has thornier stems than the red pitaya plant. Its fruits are characterised by their bright red and purple colour due to the anthocyanin pigment and have red skin and dark red pulp as shown in Fig. 1A, B and 1C. They are oval to spherical and can weigh up to 1 kg, with pear-shaped black seeds that are 10 mm in size [7] (see Fig. 2).

The yellow pitaya plant, or S. megalanthus, is native to northern South America and is produced commercially for its golden fruits. This type of cactus has a yellow shell and white pulp, with oval-shaped fruits smaller than other varieties. The inner space is white, although it can be pink when hybridized as shown in Fig. 1D. The fruits of this variety are sweeter than those of the red varieties and contain stimulants for the heart. Overall, the pitaya plant comes in several varieties, each with unique characteristics, including the famous red pitaya plant with white pulp, the Costa Rican pitaya plant with its bright red and purple fruits, and the yellow pitaya plant, which is sweeter and contains stimulants for the heart. As the demand for Pitaya grows, more exotic fruit varieties will likely be cultivated [8,9].

The pitaya plant, also known as dragon fruit, is a climbing cactus plant type of perennial tree that can live for up to two decades.

Table 1
Ingredients and minerals present in 100 g of pitaya fruit.

Element	Amount	Nutrients	Amount
Water	87 g	Vitamin B1	0.04 g
Protein	1.1 g	Vitamin B2	0.05 g
Fat	0.4 g	Vitamin C	20.5 g
Carbohydrates	11.0 g	Calcium	8.5 g
Iron	1.9 g	Phosphorus	22.5 g

Figure 1. Three different Selenicereus species of Pitaya (A) S. undatus (B) & (C) S. costariscensis and (D) represent S. megalanthus - DGF3 (d) (Abirami et al., 2021).

These plants thrive in lowlands with a tropical climate, making them ideal for cultivation in many countries. When growing pitaya plants, it is advisable to support them with a trellis system to facilitate their vertical growth, as the plants have long stem segments. Pitaya plants prefer moist and warm climates and nutrient-rich soil, making them well-suited for tropical and subtropical regions. These plants are known for tolerating drought and surviving with as little as 63.5–127 cm of water per year. However, excessive watering can lead to reduced blossoms or distorted fruits, while exposure to heavy rains can cause flowers to drop and fruits to rot. It is important to note that pitaya plants are sensitive to cold weather, and low temperatures can harm plant growth. Therefore, growers in colder climates may need special precautions to protect their plants from frost damage. Moreover, cultivating pitaya plants requires specific growing conditions, including a warm and moist climate, nutrient-rich soil, and adequate watering. As more countries seek to cultivate this exotic fruit, it is essential to understand the plant's needs to ensure successful production [8].

The pitaya plant is cultivated in several countries across Asia, including East Asian, South Asian, and Southeast Asian countries such as Cambodia, Thailand, China, Malaysia, Vietnam, Sri Lanka, the Philippines, Indonesia, and Bangladesh.

Vietnam is the largest producer in the world of the pitaya plant, which is called "pitaya" or "petahaya." also, and the Vietnamese

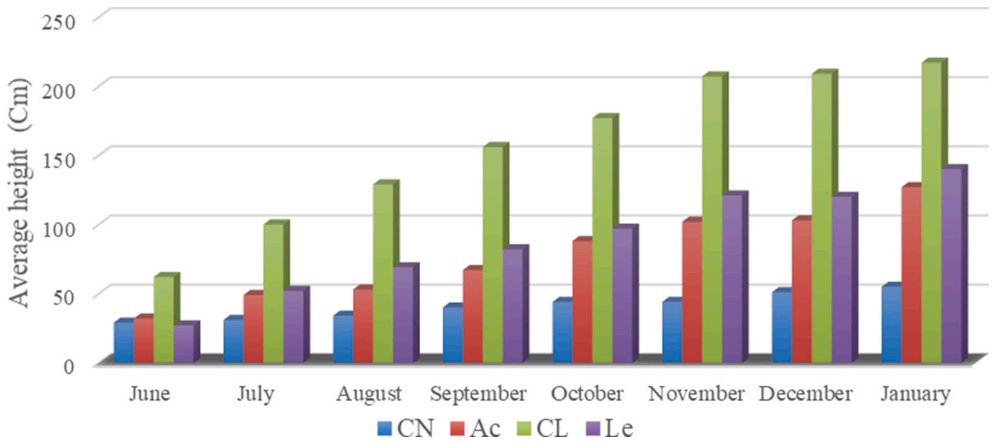

Figure 2. Average height of pitaya plant for S. undatus cultivar.

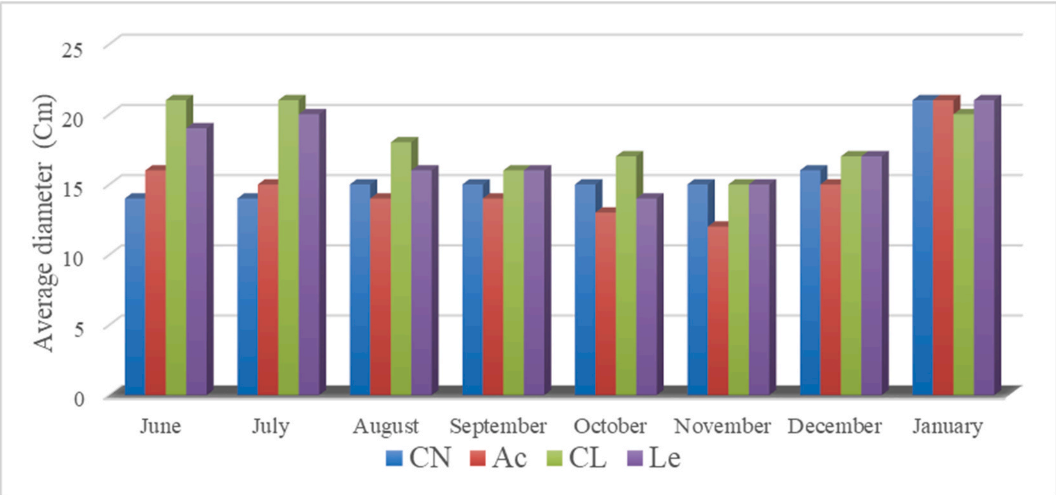

Figure 3. *Average diameter of pitaya plant for S. undatus* cultivar.

dragon fruit is preferred in the world as its size, colour, and taste characterise it, and all these specifications come from the warm climate and fertile land. The pitaya plant is the fruit of the people cultivated by France in Vietnam for more than 100 years, and it is the only country in Southeast Asia where the pitaya plant has been grown with an increasing concentration on a large commercial scale in large areas. Furthermore, Tien Giang spread in other places (Vietnam is characterised by the spread of the white pitaya plant, one of the most common types of pitaya plant, and red dragon fruit). A high percentage of Vietnam's population and economic assets are located in the coastal lowlands, deltas and rural areas, which explains why Vietnam is ranked among the five countries most likely to be affected by climate change. In particular, climatic changes affect agricultural production due to increased saline water intrusion and the lack of irrigation water in the dry season. Interestingly, the pitaya plant has been successfully cultivated in the mangrove areas of Vietnam due to its high adaptability to grow under harsh environmental conditions, becoming a valuable asset to the country's sustainable development [9,10].

Indonesia has intensively cultivated the pitaya plant (Selenicereus spp.) for the last 15 years, and it can now be found almost all over the country. Production centres are located in several provinces, including Riau, Kepulawan Riau, West Sumatra, East Kalimantan, and the island of Java. The most common cultivar is the red Pitaya, and areas around 800 m above sea level are considered suitable for cultivating this fruit. The productivity of the pitaya plant in Indonesia is impressive, with an initial ITFRI survey and farmers' experiments indicating a yield of about 24–30 tons/ha/year. In Indonesia, the pitaya plant has two types of flowering and fruiting patterns. The first pattern occurs throughout the year in regions close to the equator, while the second pattern, which occurs in Java Island, has a flowering and fruiting period of 6–7 months from October to April. Although Indonesian pitaya products are mainly supplied to local markets, a small percentage is exported to Singapore, and the country also imports Pitaya from Vietnam, China, and Thailand [11].

Pitaya cultivation in Asia is a growing industry, with different countries adopting unique cultivation methods and conditions to produce high-quality fruit. The versatility and adaptability of the pitaya plant make it an attrActival crop for farmers worldwide, with the potential for even more countries to join the global pitaya market in the future [8,9].

Saudi Arabia's interest in cultivating the pitaya plant can be attributed to its potential as a profitable and sustainable crop that requires less water than other crops. Additionally, the fruit is known for its nutritional value and health benefits. The pitaya plant is a good source of minerals, glucose, fructose, dietary fibre, and vitamins and contains water-soluble fibre, vitamin C, and antioxidants such as betalains, flavonoids, and hydroxycinnamates [8]. Studies have shown that the nutritional content of dragon fruit varies depending on the species, agricultural methods, growth area, and harvest time. Overall, the increasing cultivation of the pitaya plant in recent years is due to its health and economic benefits, as it is a source of functional materials rich in fibre, vitamins, minerals, phytochemicals, and antioxidants. These compounds have been found to have many health benefits, including improving digestion, reducing harmful cholesterol levels, strengthening the immune system, and protecting against bacteria and fungi. The fruit has also been used to treat diabetes and heart disease [2,9].

The pitaya plant's nutritional value varies based on environmental conditions and type. It is a rich source of essential minerals like potassium, phosphorus, sodium, magnesium, and vitamins [10]. The fruit's nutritional content varies depending on its type, origin, and harvest time. The Pitaya contains vitamins, minerals, and a high antioxidant activity. The early stem contains ascorbic acid, potentially preventing diseases like anaemia and weakness. The fruit's small black seeds also contain high-quality essential fatty acids and phytochemical compounds with antimicrobial activity.

Furthermore, the peels of the dragon fruit have a high potential for use as a natural dye. The adaptability of the pitaya plant to different soils and temperatures also makes it an attrActival crop for Mediterranean farmers. However, factors such as season, climate, cultural methods, water availability, transportation, and storage can affect the yield and value of the fruit, as well as its nutritional content. Its adaptability to different environments and low water requirements make it a sustainable and profitable crop for farmers in many world regions [6,11,12].

- This study aims to determine whether different varieties of pitaya plants, specifically S. Undatus and S. Costaricensis, can thrive and be successfully cultivated in the Asir region of Saudi Arabia.
- To measure and compare the growth and developmental aspects of the selected pitaya plant varieties under the local climatic conditions, including morphological and physiological characteristics.
- To identify the most effective fertilisation treatments for enhancing the growth and productivity of the pitaya plants.
- Record and assess disease treatments and management strategies for pitaya plants, drawing from prior research and practices applied on the Sirhan farm in the Asir region.
- To compare the performance and adaptability of the two pitaya varieties, S. Undatus and S. Costaricensis, under the given climatic conditions and treatments to determine which may be more suitable for cultivation in this arid region.
- To generate data and findings that can inform and guide the cultivation of pitaya plants in similar arid or desert-like climates, potentially offering insights and recommendations for other regions interested in growing this crop in challenging environmental conditions.

2. Materials and methods

2.1. Study site

The study was conducted in the Asir region of Saudi Arabia, which has a 76,693 square kilometre area with a 2000 m height gradient. The study aimed to investigate the most suitable types of pitaya plants for the climatic conditions in the Kingdom of Saudi Arabia. The area has a distinct climate, with mild summer temperatures and maximum temperatures below 24° Celsius in mountainous areas. The average temperature is higher than the global average and is 10° Celsius lower than in other regions of the Kingdom. The area receives 500 mm of rain annually, with more rain falling in the summer and spring because of the topography and vegetation cover.

The study's key considerations include randomisation, replication, control groups, treatment details, sample size, experimental controls, data recording and management. Randomisation ensures treatment effects are not influenced by plant size or location. Replication allows for the assessment of variations within and between treatments, enhancing the reliability of results. A control group (CN) serves as a baseline for comparison. Treatment details, such as compositions, application methods, and timing, enhance the study's reproducibility. The sample size should be assessed for adequacy, considering potential environmental factors. Clearly defining and standardising pitaya plant morphological characteristics measurement methods helps ensure accurate and consistent data. Effective data recording and management are crucial for maintaining data integrity, with quality control procedures in place to detect and address errors.

2.2. Experimental design

2.2.1. Plant selection

Two pitaya cultivars were selected for this study: Selenicereus undatus (S. Undatus) and Selenicereus costaricensis (S. Costaricensis). These cultivars were chosen due to their relevance and potential suitability for cultivation in the arid Asir region of Saudi Arabia.

2.2.2. Randomisation and replication

Randomisation was employed when assigning pitaya plants to different treatments to eliminate bias. Replication was ensured by using multiple plants for each treatment, enhancing the precision of estimates and the ability to detect treatment effects.

2.2.3. Control groups

A control group (CN) was included in the study to serve as a baseline for comparing the effects of different treatments. The control group received no treatment, providing a reference point for assessing treatment impacts.

2.2.4. Treatments

Four treatments were implemented: Control (CN): Untreated pitaya plants were examined to assess natural growth. Actival Fertiliser coefficient (AC): Pitaya plants were treated with a specific Actival fertiliser. Klebak Fertilizer coefficient (KL): Pitaya plants received Klebak fertiliser which contains marine algae rich in auxins and amino acids. Leaf Compost with Volcanic Stone (Le): Pitaya plants were treated with a combination of leaf compost and volcanic stone.

2.3. Treatment details

2.3.1. Actival Fertiliser (AC)

Actival fertiliser refers to fertilisers that contain Actival ingredients other than basic nutrients required for plant growth. Height, diameter and branching after AC treatment were documented.

2.3.2. Klebak Fertilizer (KL)

Klebak fertiliser treatment was administered to pitaya plants. Height, diameter and branching were documented throughout the study.

2.3.3. Leaf compost with volcanic stone (Le)

The treatment involving leaf compost with volcanic stone was implemented with specific details on compost composition, volcanic stone application, and timing. Height, diameter and branching were documented throughout the study.

2.4. Data collection

Data collection spanned eight months, from June to January, to capture the growth and development of pitaya plants over an extended period. This duration allowed for the assessment of long-term treatment effects.

2.4.1. Morphological measurements

Morphological measurements, including plant height, diameter, and branching, were recorded regularly during the study period. The measurement methods were standardised for consistency.

2.5. Data analysis

Data analysis was conducted using Microsoft Excel and R statistical software (version 4.3.0).

2.5.1. Statistical models

Statistical models were employed to compare treatment effects, including Analysis of Variance (ANOVA). The models considered factors and interactions relevant to the study's objectives.

2.5.2. Randomisation and replication analysis

Randomisation was applied, and replication was analysed to assess variations within and between treatments, ensuring the reliability of results.

3. Results

The findings showed that the most effective treatment for both S. undatus and S. costaricensis was the Klebak fertilizer, which contains marine algae rich in auxins and amino acids. Additionally, S. costaricensis benefited from the treatment of tree leaves with volcanic stone. The leaves provided vital organic nutrients for plant growth, while volcanic stone helped to keep the soil moist and allowed for correct drainage. S. costaricensis also shown increased cultivation resilience and adaptability, probably as a result of its native environment in the temperate climate of Mexico. The Actival fertiliser coefficient and Klebak fertiliser coefficient treatments significantly increased plant height, while. S. costaricensis outperformed S. undatus in height, diameter, and branching, suggesting it is better suited for pitaya cultivation in the arid Asir region.

3.1. Cultivar viability

Both S. undatus and S. costaricensis pitaya cultivars showed promise for successful cultivation in the arid Asir region of Saudi Arabia. This suggests that pitaya farming could be a viable option in this climate.

3.2. Growth and development

The Actival fertiliser coefficient (AC) treatment significantly boosted the height of S. undatus pitaya plants compared to those in the control group (CN). This indicates that using the Actival fertiliser coefficient can lead to taller plants. The Klebak fertiliser coefficient (KL) treatment was highly effective for both S. undatus and S. costaricensis, resulting in continuous growth over eight months. This treatment showed significant promise for promoting pitaya plant growth in arid conditions. In all treatments, S. costaricensis consistently exhibited taller average plant heights compared to S. undatus. This demonstrates that S. costaricensis has a natural advantage in terms of height under the given arid climate conditions.

3.3. Fertilisation methods optimisation

The Klebak fertiliser coefficient (KL) treatment stood out as exceptionally effective in enhancing the growth of pitaya plants, positively affecting both height and diameter. This suggests that Klebak fertiliser may be key in maximising pitaya growth in arid regions. The Leaf compost with volcanic stone (Le) treatment also positively impacted plant growth. It helped enhance both height and diameter, albeit with some fluctuations. This treatment offers an organic alternative for promoting pitaya growth.

3.4. Varietal comparison

S. costaricensis consistently outperformed S. undatus regarding height, diameter, and branching across all treatments. This indicates that, in the arid Asir region of Saudi Arabia, S. costaricensis is better suited for pitaya cultivation due to its superior growth characteristics.

Significant findings that correspond to the objectives of the study are for cultivation in the arid climate of the Asir region of Saudi Arabia; possibilities for cultivation for the S. undatus and S. costaricensis cultivars were assessed to be viable. Compared to the CN treatment, the AC greatly raised the S. undatus pitaya plants' average height, indicating both cultivars' potential development and growth. For S. undatus, the CL treatment produced the highest average height, with consistent development seen from June to January. Compared to S. undatus, S. costaricensis showed greater average heights across all treatments, with AC and CL treatments exhibiting the greatest increase. S. undatus and S. costaricensis pitaya plants grew more quickly after receiving the CL treatment, indicating potential for fertiliser. Across all treatments, S. costaricensis consistently outperformed S. undatus in terms of height, diameter, and branching, indicating that these cultivar species are better suited to grow in the arid climate of Saudi Arabia.

4. Discussion

The study analysed the average height of S. undatus pitaya plants under four treatments: CN, AC, CL, and Le. Results showed that AC resulted in higher average heights, while CL showed the highest height increase. Le showed a steady increase in height throughout the months.

The study analysed the average diameter of the S. undatus cultivar of the pitaya plant under different treatments. The results showed that the plant's average diameter in the control group increased gradually from 14 cm in June to 21 cm in January. The AC

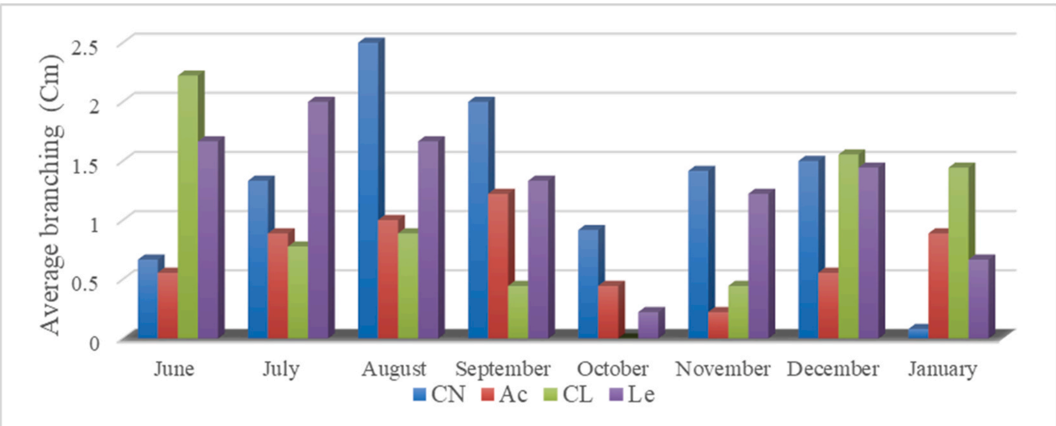

Figure 4. Average branching in the pitaya plant, cultivar S. undatus.

treatment increased the plant's diameter in June and July, while the Klebak fertiliser coefficients treatment significantly increased it.

The study analysed the average branching of pitaya plants under various treatments, with the highest number observed in June in the Klebak fertiliser treatment (see Fig. 4). The Actival fertiliser treatment had lower branches than the control treatment. Leaf compost with volcanic stone treatment showed fluctuating branching patterns, suggesting the type of fertiliser and year also affect branching. The branching patterns, aerial roots, shape of whole plant, stem and roots can be seen in Fig. 5A–H.

Fig. 6 shows the average height of the pitaya plant for S. costaricensis cultivar under different treatments. The CN treatment had an average height of 80 cm, increasing to 146 cm in January. The AC, CL, and Le treatments showed rapid growth, with the Actival fertiliser coefficients treatment having the highest growth rate (see Fig. 7).

The study evaluated four treatments on pitaya plants from June to January: control, Actival fertiliser, Klebak fertiliser, and Leaf compost with volcanic stone. The results showed that AC had the highest average diameter, with 16–21 cm during all months. The control treatment had the smallest diameter, while CL and Le's had similar diameters. The study suggests that Actival fertiliser can improve pitaya plant growth and development, but further research is needed to explore its effects on other growth parameters and fruit quality.

The average branching of the S. costaricensis cultivar of the pitaya plant was analysed under four different treatments from June to January (see Fig. 8). The CL treatment showed the highest average branching (2.222), followed by the Le treatment (1.666) and the lowest CN treatment (0.666). In July, the Le treatment had the highest average branching, followed by the CN treatment (1.333). The branching patterns, morphology, aerial roots, shape of whole plant, stem, thorns and roots can be seen in Fig. 9A–F.

The figure compares the average height of two pitaya plant cultivars, S. costaricensis and S. undatus, in all four treatments. S. costaricensis had a significantly higher average height in the CN treatment (131.75 cm) and AC treatment (170.25 cm) compared to S. undatus (77.625 cm). This suggests that S. costaricensis has greater growth potential, possibly due to genetic or environmental factors (see Fig. 10).

The study uses various treatments to compare the average diameter of pitaya plants, S. costaricensis and S. undatus. The control treatment had an average diameter of 15.5, while the undatus had an average diameter of 15.625. The Actival fertiliser treatment resulted in an average diameter of 16.37, while the Klebak fertiliser treatment resulted in an average diameter of 16.37. The Leaf compost with volcanic stone treatment produced an average diameter of 16.37, while undatus had an average diameter of 17.25.

The study compared the average branching of two pitaya plant cultivars, S. costaricensis and S. undatus, and found that S. costaricensis had higher average branching in all treatments (see Fig. 12). The control treatment had an average branching of 1.88, while the AC treatment had an average branching of 1.52, the CL treatment had an average branching of 2.34, and the Le treatment had an average branching of 2.11. Fig. 14A and B shows class S. undatus and class S. costaricensis, whereas, 14A1, A2 and A3 shows thorns, branching and stem shape of class S. undatus. Fig. 14B1, B2, and B3 shows spines, branching and shape of the stalk of class costaricensis. Costaricensis could be attributed to genetic factors and environmental conditions. The S. undatus variety and S. costaricensis variety can be seen in Fig. 13A and B, whereas, Fig. 13A1, A2 and A3 shows the parts of the whole plant, the aerial roots and the ground roots, and Fig. 13B1, B2 and B3 shows the parts of the whole plant, the aerial root and the underground roots.

Plants are associated with and bound to have diseases because of different factors such as their water content, environmental factors, and the treatment they are being given. In a study, A bacterial soft rot disease, predominantly caused by *Enterobacter cloacae*, was found in dragon fruit plants by researchers in Peninsular Malaysia. The disease was discovered in 11 of the 43 locations, with Ayer Hitam Kedah having the worst cases. With 17.33 % of plants affected, Johor had the highest incidence. The disease was discovered to

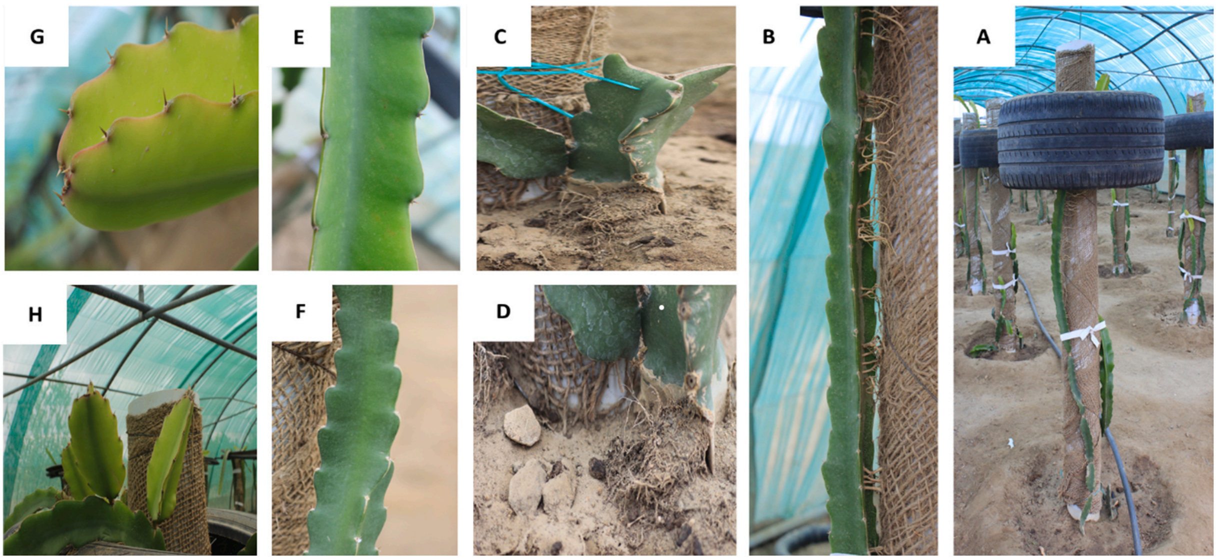

Figure 5. Morphology of the pitaya plant, the cultivar S. undatus. (A) Shows the shape of the whole plant (B) Shows the aerial roots (C–D) Shows the shape of the ground roots (E–F) Shows the shape of the stem (G) & (H) Shows the shape of thorns.

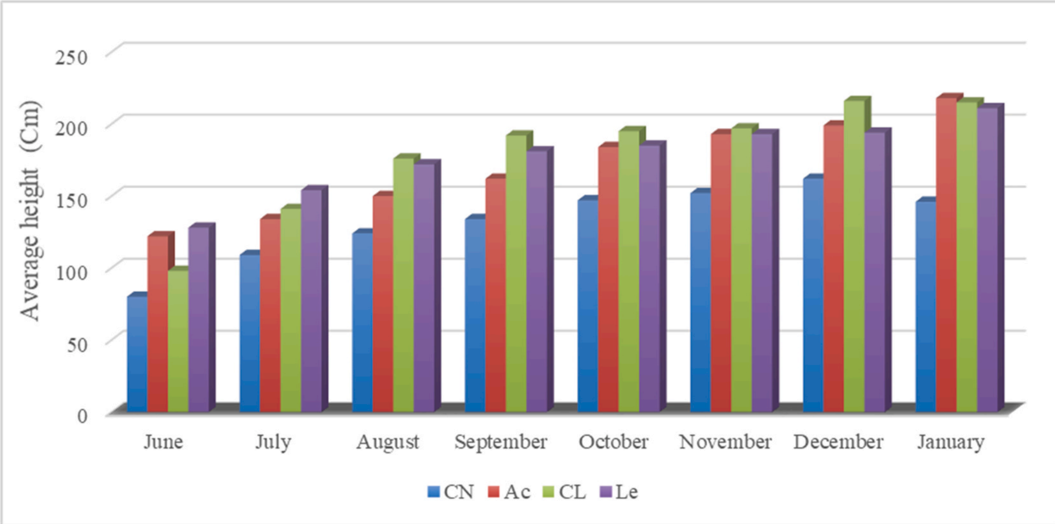

Figure 6. Average height of pitaya plant for S. costaricensis cultivar.

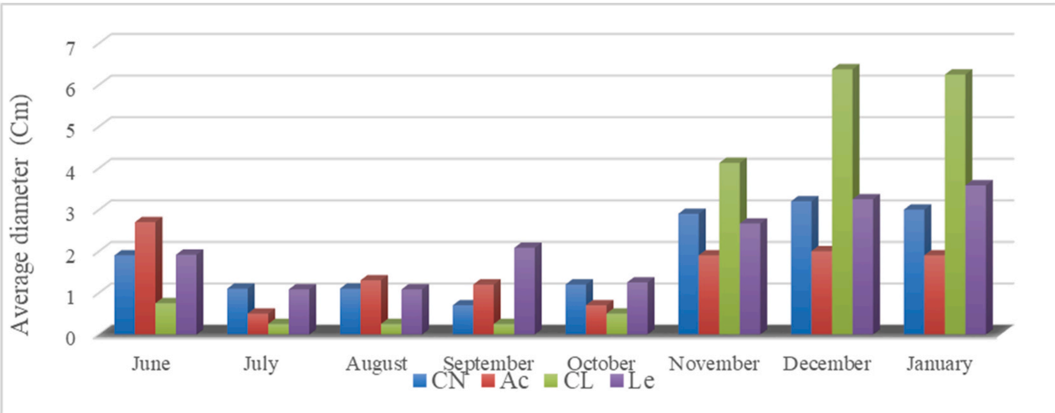

Figure 7. Average diameter of pitaya plant for S. costaricensis cultivar.

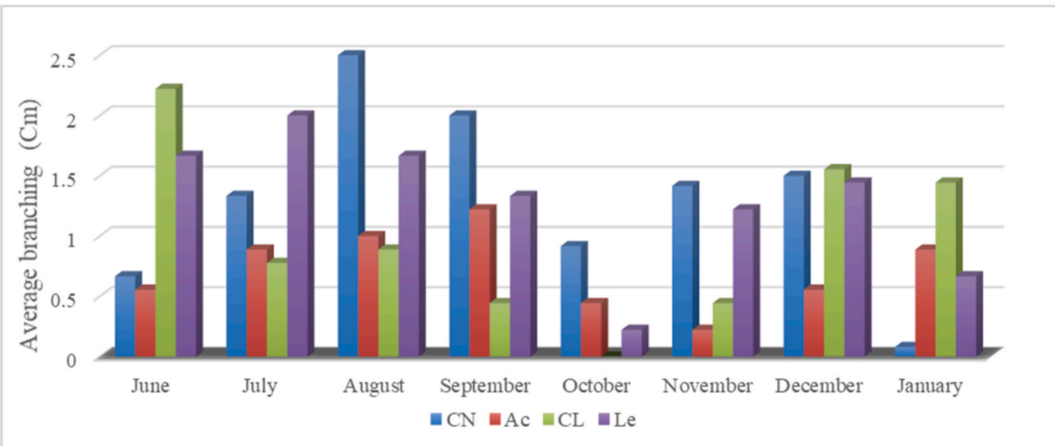

Figure 8. presents the Average branching of the S. costaricensis cultivar of the pitaya plant under four different treatments.

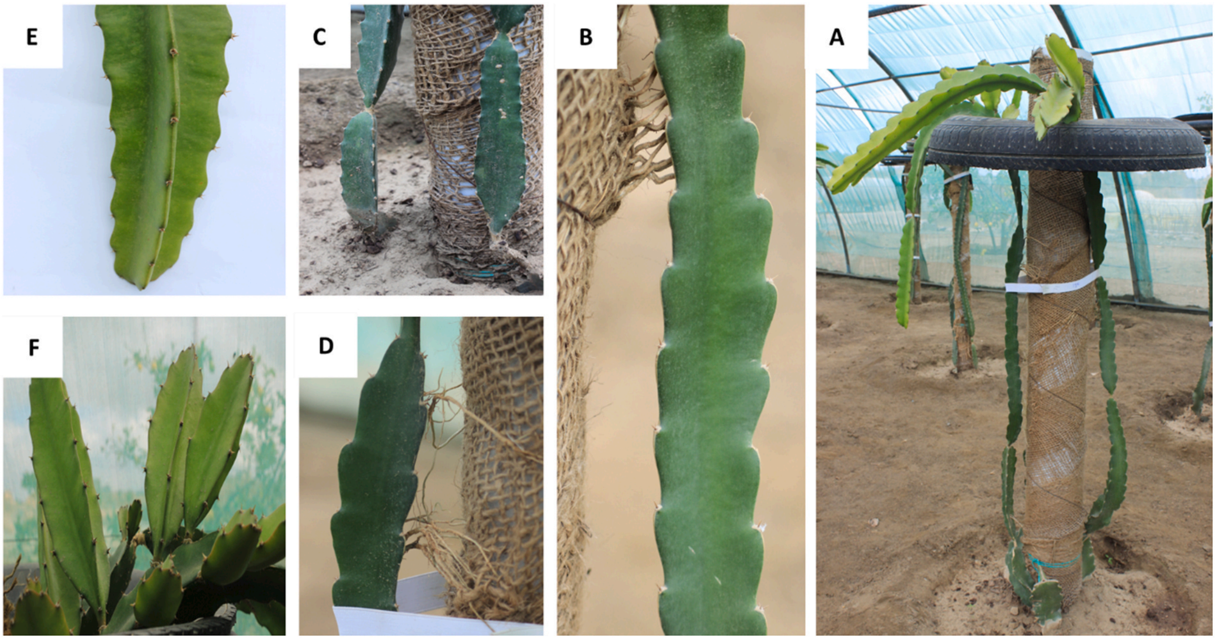

Figure 9. The morphology of the petaya plant cultivar S. costaricensis (A) Shows the shape of the whole plant (B) Shows the aerial roots (C) Shows the shape of the ground roots (D) Shows the shape of the stem (E) Shows the shape of thorns (F) Shows the branches.

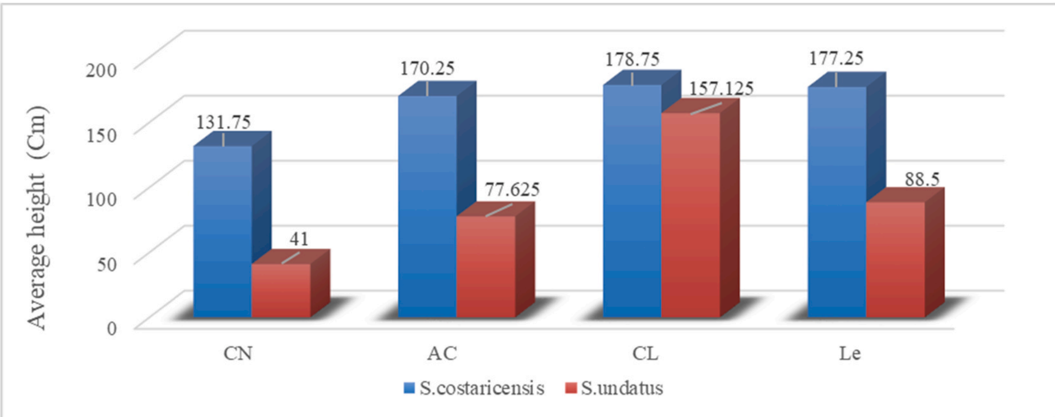

Figure 10. Comparison of average petaya plant height between S. undatus and S. costaricensis cultivars.

be more prevalent in colder, higher-altitude regions and less prevalent in warmer regions. This is the first scientific account of this illness in Peninsular Malaysia, suggesting that plant conditions and environmental elements like temperature and altitude impact the disease's occurrence (13). In another study, Researchers examined how the growth of dangerous fungi affected the temperature, pH, and salinity of dragon fruit trees. They discovered that fungi require a temperature of 25 °C to thrive, while 35 °C is too hot. Extreme pH values inhibited fungi growth, whereas excessive salt concentrations might slow it down. It has been discovered that beneficial bacteria, such as Burkholderia multivorans, are effective at inhibiting the growth of fungi. This knowledge can create strategies to protect dragon fruit plants from illnesses and enhance crop development and shelf life. The shelf life of fruit can also be increased by properly controlling environmental factors (14). The quality of pitaya plant growth can also be enhanced, and many studies have been done on this to provide promising insights. Researchers conducted a two-year field experiment to determine the impact of combining biochar and organic fertiliser on the soil and quality of red Pitaya. They tested different biochar rates and organic fertiliser levels. The results showed that using organic fertiliser alone improved soil quality and red pitaya yield. However, when combined with biochar, it worked even better. The combination of 3 % biochar and 45 tons per hectare of organic fertiliser yielded the highest red pitaya yields in 2019 and 2020. The most profitable treatments were C3F2 and C6F1 (15). Another study examined the use of organic biogas residual fertiliser with conventional and cattle manure treatments on dragon fruit productivity and quality. The yield and sugar-acid ratio significantly increased compared to standard fertilisation, with a VCR value 4.95. Biogas residue organic fertiliser increased yield per

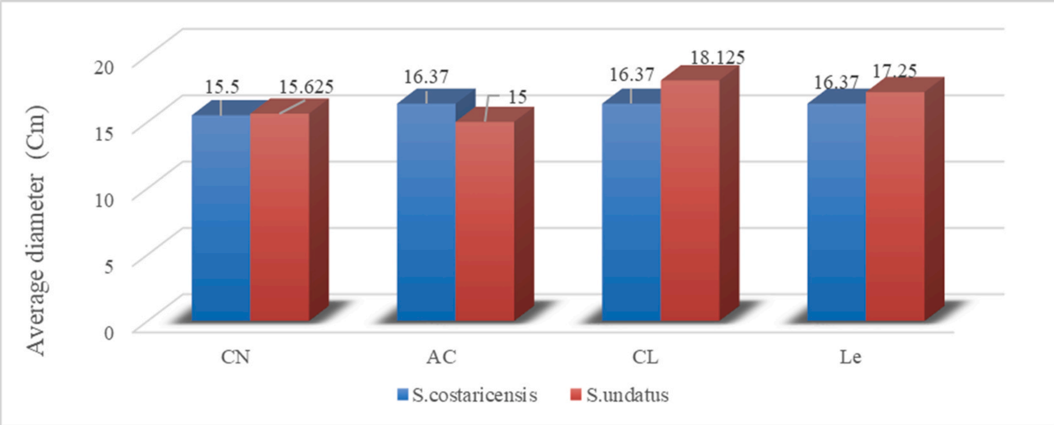

Figure 11. Comparison of average petaya plant diameter between S. undatus and S. costaricensis cultivars.

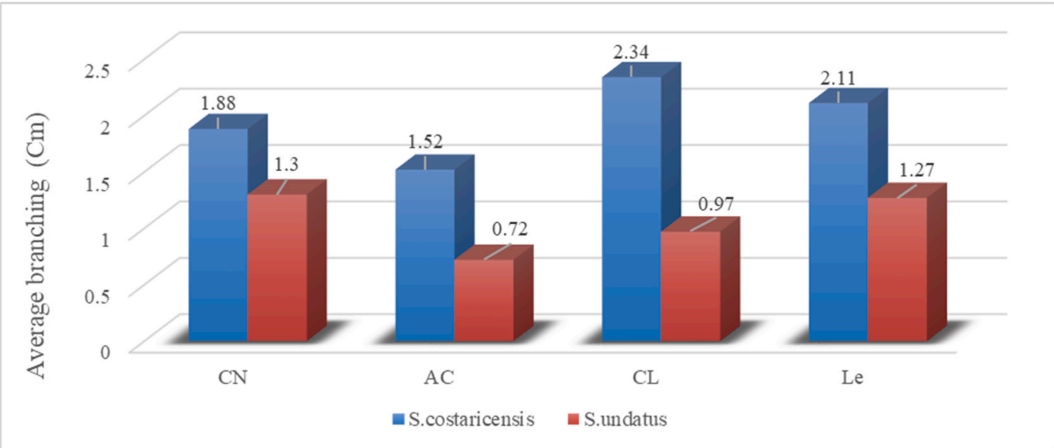

Figure 12. Comparison of average petaya plant diameter between S. undatus and S. costaricensis cultivars.

hectare by 9.82 % and sugar-to-acid ratio by 5.58 % (16).

Another study reviews diseases affecting dragon fruit, such as anthracnose, fruit and stem rot, stem canker, and cactus viral disease. The study discusses various disease management approaches, including temperature management, hot water treatment, and gamma irradiation (17). The post-harvest management of dragon fruit is addressed in a study focusing on conventional and non-conventional methods. Traditional farming methods and manual control are used, while alternative approaches use more recent substitutes for synthetic fungicides. A tropical fruit called dragon fruit can be kept at 10 °C for 4 weeks, and if pre-cooled to 3 °C, can be kept for up to 6–8 weeks with improved quality. White-fleshed dragon fruit, however, can be kept at 5 °C (18).

Dragon fruit is a nutritious plant with numerous health benefits, including immune system boost and weight management. Its yield and nutritional value vary based on species, cultivation techniques, and harvest period. The natural colour of the peel is promising. Dragon fruit's high market prices attract consumers, but little is known about its production. Further research on dragon fruit production and health benefits could increase its market. Recent studies reveal significant findings on dragon fruit cultivation, diseases, and post-harvest management. Altitude and temperature play a role in the prevalence of bacterial soft rot disease, while temperature, pH, and salinity influence fungal growth. Combining biochar and organic fertiliser enhances soil quality and yield, while post-harvest management practices like temperature control and pre-cooling extend fruit shelf life.

5. Conclusions

This study evaluated the growth of two pitaya cultivars, S. undatus and S. costaricensis, in the arid Asir region of Saudi Arabia under various treatments. The marine algae-enriched Klebak fertiliser treatment successfully accelerated the growth of S. undatus. S. costaricensis also grew substantially better with the addition of Klebak fertiliser and volcanic stone treatment, which may be related to the plant's Mexican origins and better resistance and adaptation. These results offer helpful advice for growing Pitaya under similar climatic conditions, highlighting the significance of specialised fertilisation and environmental care for optimum development.

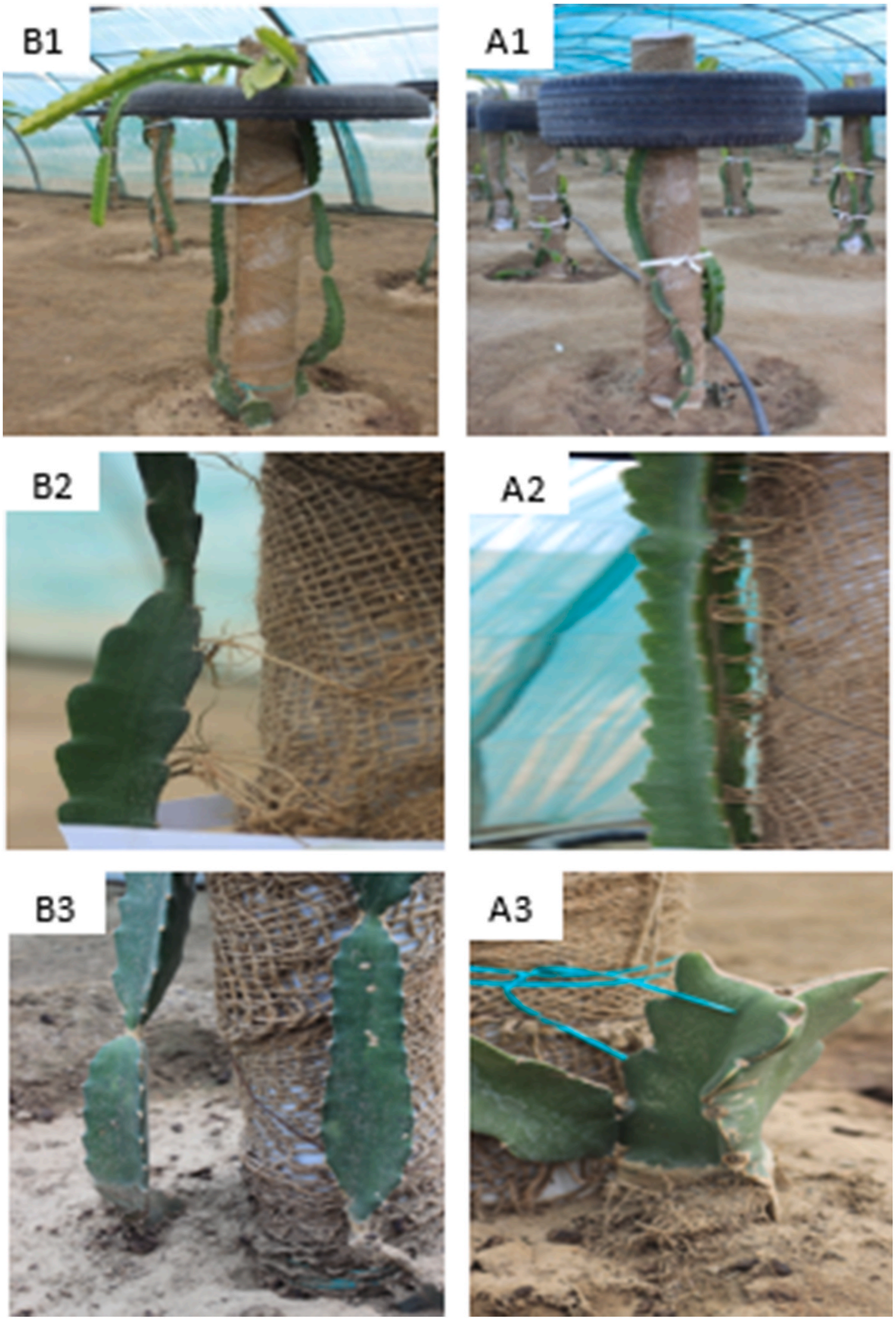

Figure 13. A) shows the S. undatus variety, and B) shows the S. costaricensis variety, where (A1) shows the parts of the whole plant, (A2) shows the aerial roots, (A3) shows the ground roots, and (B1) shows the parts of the whole plant and (B2) shows the aerial roots and (B3) shows the underground roots.

5.1. Strength and implications

➢ The study evaluates two pitaya cultivars, S. undatus and S. costaricensis, under different treatments, providing insights into their growth and suitability for arid climate cultivation.
➢ The most effective treatment is Klebak fertiliser enriched with marine algae and volcanic stone application.
➢ Comparative analysis reveals S. costaricensis's better growth and resistance attributes.
➢ Environmental factors like soil moisture preservation and drainage promote pitaya growth.

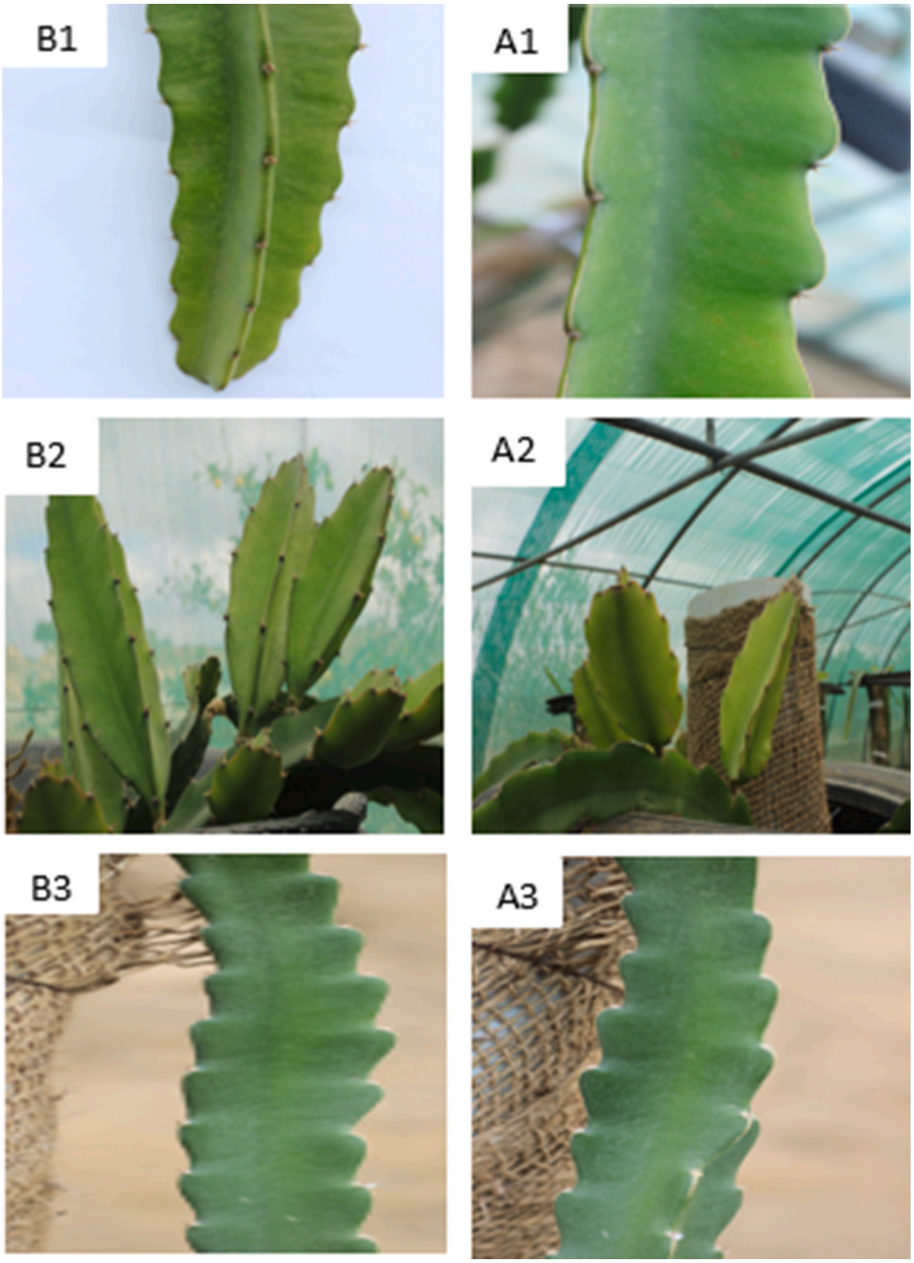

Figure 14. (A) class S. undatus and (B) show class S. costaricensis where (A1) shows thorns, (A2) shows branching, (A3) shows stem shape, (B1) shows spines, (B2) shows branching, B3) Shows the shape of the stalk.

➢ Implications include crop diversification, resource efficiency, climate adaptation, and export opportunities.
➢ Further research is needed to understand other growth parameters and fruit quality attributes.

5.2. Limitations

➢ The study on pitaya cultivation in Saudi Arabia's Asir region has limitations, including limited geographic scope, short duration, and focus on specific varieties.
➢ The study primarily compared two pitaya cultivars, S. undatus and S. costaricensis, but did not explore a broader range of pitaya varieties.
➢ The study's small-scale size may limit its ability to fully represent the challenges and opportunities of large-scale commercial pitaya cultivation.

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Author contribution statement

Rahmah Al-Qthanin: Conceived and designed the experiments; Performed the experiments; Analysed and interpreted the data; Contributed reagents, materials, analysis tools or data and wrote the paper.

Affra Mirghni Mohamed Elhaj Salih, Fatimah Mohammed A Alhafidh and Sarah Amer Mohammed Almoghram: Performed the experiments; Analysed and interpreted the data; Contributed reagents, materials, analysis tools or data and wrote the paper.

Ghada Abdulrahman Alshehri and Nada Humoud Alahmari: Analysed and interpreted the data; Contributed reagents, materials, analysis tools or data and wrote the paper.

Data availability statement

No data was used for the research described in the article.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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