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Optimizing pineapple fruit production through growing media selection

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ABSTRACT

Purpose: Pineapple (*Ananas comosus* L.) is a tropical fruit of significant economic importance worldwide. The cultivation of this crop is influenced by various factors, including the growth media, which directly affect plant growth, yield, and fruit quality. Therefore, selecting the appropriate growth medium is crucial for achieving optimal pineapple production. **Research method:** This study was conducted over four years and evaluated five growing medium treatments: 1) a control consisting of field soil, sand, and animal manure; 2) peat moss and perlite; 3) peat moss, perlite, and sand; 4) cocopeat and perlite; and 5) cocopeat, perlite, and sand. Each treatment was replicated three times, with six pots per replicate, arranged in a randomized complete block design under a shade system with drip irrigation in Chabahar, located in Sistan and Baluchestan province, Iran. **Findings:** The results indicated that the cocopeat, perlite, and sand mixture significantly outperformed the other treatments in terms of vegetative growth and yield. The fruit weights with crown for the main plant and ratoon grown in this medium were 1208 and 851 g, respectively, with corresponding yields of 101,173 and 62,240 kg/ha, respectively. A combination of cocopeat, perlite, and sand has proven to be the optimal growth medium for pineapple cultivation. **Research limitations:** No limitations were found. **Originality/Value:** This study demonstrated that this specific mixture significantly enhanced vegetative growth, fruit yield, and overall plant health compared with the other tested media. These results suggest that this growing medium can be effectively used for pineapple production in a controlled environment.

INTRODUCTION

Pineapple (*Ananas comosus* (L.) Merr.) is a perennial herb belonging to the Bromeliaceae family and is native to the tropical regions of America. Its distinctive fruit, composed of fused berries, develops from a flowering plant. Costa Rica, the Philippines, and Brazil, which have favorable tropical climates, have become major pineapple-producing countries (Aruna, 2019). Indonesia, the Philippines, and Costa Rica were the top pineapple producers globally in 2022. Costa Rica's output alone reached 2.9 million metric tons each year. The world harvested approximately 29.4 million metric tons of pineapples worldwide during the same period (World Population Review, 2023). Pineapple, offers a combination of exceptional juiciness, vibrant flavor, and numerous health benefits. It's a source of essential nutrients, including calcium, potassium, vitamin C, carbohydrates, fiber, and various minerals. Low in fat and sodium (Sabahelkhier et al., 2010). Minerals present include calcium, chlorine, potassium, phosphorus, and sodium (Dull, 1971). Pineapple, a tropical species, thrives optimally within a temperature range of 22–32°C, with daily fluctuations of 8–14°C. Exceeding 32°C, particularly in conjunction with intense sunlight, can impair growth and cause sunburn during fruit maturation. Conversely, temperatures below 20°C hinder development and induce premature flowering, complicating cultivation, and increasing fruit loss (Bartholomew et al., 2003). Despite the limited tolerance to temperatures above freezing, the plant is highly susceptible to frost damage. Pineapple exhibits a remarkable tolerance to drought conditions. Its leaves possess specialized water-storage parenchyma cells, which enable them to retain moisture during periods of aridity. Moreover, a thick waxy cuticle covers the leaves, and the stomata are concentrated in sunken areas on the underside of the leaf (Nakasone & Paull, 1998). Although pineapple can thrive in regions with high annual rainfall (ideally 1500 mm), it can also be cultivated in areas receiving as little as 500 mm. In regions with less than 1500 mm of annual rainfall, supplemental irrigation, especially during the hot and dry seasons, is essential. Despite their drought resistance, prolonged dry spells can significantly harm pineapple plants. For commercial fruit production, pineapple requires 1000-1500 mm of annual rainfall supplemented by irrigation, and 70-80% relative humidity (Singh, 1995). Owing to its shallow root system, pineapple benefits from frequent, shallow irrigation. The optimal growth temperature for pineapple is reported to be 32°C during the day and 20°C at night. For every degree of Celsius deviation from these optimal temperatures, growth is reduced by approximately 6%. Intense sunlight and temperatures exceeding 35°C can lead to sunscald fruit (Anonymous, 2013). Cool temperatures delayed growth, resulting in smaller, more serrated leaves, increased sucker production, smaller fruits, cloudy fruit flesh, increased acidity, and reduced sugar content (Bartholomew & Kadzimin, 1977). Pineapples cannot tolerate low temperatures or prolonged exposure to temperatures below 7-10°C. Once a plant reaches a certain vegetative growth stage, cool nights can induce flowering. High temperatures (above 28°C) disrupt the formation of compounds necessary for flowering, thereby reducing flowering ability. Conversely, low temperatures, bright light, and complete shade are detrimental to plant growth (Bartholomew & Kadzimin, 1977). Fruit weight was directly correlated with light exposure during the growth period. Increased light intensity decreases fruit acidity but does not affect the total soluble solids content. Cloudy days reduced plant growth and fruit size. Some cultivars, such as those in the Queen group, are susceptible to sun scalding during fruit development when exposed to intense sunlight. Cultivars such as Smooth Cayenne and Cayenne are day neutral and can flower at any time of the year. However, pineapple can be considered as a short-day plant, although short days are not strictly required. Interrupting dark periods and providing supplementary light can inhibit flowering. Cool night temperatures enhance short-day effects (Nakasone & Paull, 1998). Optimal pineapple cultivation necessitates annual sunlight exposure between 2,500 and 3,000 h, equivalent to 7-8 hours daily. A minimum of 1,200-1,500 sunlight hours were required. Shade significantly influences growth and mandates meticulous site selection for solitary or companion planting (Reinhardt, 2001).

Agricultural production, particularly rain-fed cultivation, is highly susceptible to climate variability and change, which often adversely affects horticultural productivity. Meteorological assessments indicate a global trend towards rising surface temperatures, more intense and frequent extreme precipitation events, and elevated sea levels, especially in tropical regions (IPCC, 2014). A significant challenge posed to the horticulture industry is a temperature increase of up to 4°C. Regional shifts in rainfall patterns and temperatures are expected to have detrimental consequences on horticultural production (Deuter, 2008). For instance, untimely rainfall during drought periods or suboptimal temperatures during flowering and fruit development can diminish yields and induce physiological disorders (Datta, 2013). Empirical evidence from Uganda highlights the vulnerability of pineapple cultivation to climate extremes, with farmers reporting reduced yields and increased pest and disease prevalence in 2012, attributed to prolonged drought and elevated temperatures (Mugambwa, 2014). Protected cultivation systems, such as shade netting, have gained significant prominence in the face of contemporary climate change and the associated biotic stresses. Globally, diverse shade nets are employed to shield trees from adverse environmental conditions, including hail, wind, excessive solar radiation, and pests, thereby enhancing tree health and fruit quality (Manja & Aoun, 2019). Concurrently, modifying the composition of the growing media can improve plant growth and resilience to environmental stressors. Studies have demonstrated that a variety of growing media are widely used for cultivating horticultural crops in trays, bags, and pots. The combination of soil with well-rotted manure or vermicompost is a suitable growing medium and nutrient source for plants because it is readily available and economical. Furthermore, it was concluded that cocopeat mixed with any type of organic matter outperformed cocopeat alone, which may be attributed to the supply of nutrients to the growing medium by organic matter (Agarwal et al., 2021). To optimize the growth media, careful selection of components with optimal properties is imperative. Historically, sphagnum peat has been the predominant component because of its exceptional characteristics. However, increasing concerns about peatland degradation and the imperative for sustainable practices have stimulated research on alternative substrates. A wide range of materials, including compost, wood fiber, bark, and cocopeat, have been identified as potential substitutes. Although each material possesses unique advantages and limitations, peat continues to be a critical component in many growing media, especially as a diluent (Schmilewski, 2008). The growing global demand for pineapple has intensified the need for sustainable and efficient cultivation. The choice of growing medium is a key aspect of pineapple production. This study undertakes a comparative analysis of different growing media types, focusing on their impact on pineapple plant growth and fruit quality. By identifying the most suitable substrates, this study will contribute to the development of more sustainable and economically viable pineapple production systems.

MATERIALS AND METHODS

Location and treatments

This study was conducted at the Chabahar Agricultural Research Station, located at 60° 38' 19"″ E and 25° 10' 57″ North latitude, at an altitude of 10 m above sea level. The proximity of Chabahar to the sea, its location near the Tropic of Cancer, and its exposure to the Indian monsoon and equatorial fronts contribute to a relatively warm tropical climate characterized by high humidity. It is the warmest region in the country during winter and the coolest southern port of Iran during summer. The average maximum temperature (in June) over a seven-year period was 31°C, the average minimum temperature (in January) was 19°C, and the annual average temperature was 26°C. The minimum relative humidity was 60%, and the average relative humidity was 70%. The average annual rainfall is less than 200 mm, with 64% of the rainfall occurring in winter (Chabahar, 2022).

To investigate pineapple growth and adaptation, a 2.5-meter-high shade net was constructed using galvanized poles and a green shade net providing 40% shading. The shading net covered an area of 500 m^2. The surrounding walls were enclosed in similar nets. The following are the treatments.

SSM: Control treatment consisting of an equal-volume mixture of agricultural soil, washed sand (0.5-8 mm), and manure.

PP: Equal-volume mixture of peat moss and medium-grade perlite (2-5 mm). PPS: Equal-volume mixture of peat moss, perlite, and washed sand.

CP: Equal-volume mixture of cocopeat and perlite.

CPS: Equal-volume mixture of cocopeat, perlite, and washed sand.

Six 15-liter pots (25 cm diameter) were used for each treatment in each replicate. The substrate components were mixed volumetrically and filled into pots. One rooted MD2 pineapple plantlet produced through tissue culture was transplanted into each pot. Tissue culture has been demonstrated to be a reliable and efficient method for pineapple propagation, providing benefits such as increased productivity and disease-free planting material. Therefore, tissue-cultured pineapple plantlets were used in the present study (Jackson et al., 2016). At transplanting, the plantlets had an average of 15 leaves, a plant height of 7 cm, a stem diameter of 1.5 cm, 10 roots, and a root length of 12 cm. Daily drip irrigation was applied to maintain field capacity in the root zone. All the treatments received the same foliar fertilization. No cooling or heating system was used within the shade house during the experiment. Due to the unsuitable substrate, the growth of plants in the control treatment gradually ceased, and they completely dried up after nine months, then the experiment was conducted using four treatments.

In December 2017, the plants were sprayed with 25 ppm ethephon to induce flowering. Flowering was observed in December of the same year, and fruit growth continued until harvest the following spring. Harvesting began in early July and continued until the end of that month. The largest sucker closest to the soil surface (first ratoon) was retained for the next generation, whereas other plantlets on the fruit stem and suckers were removed. Ethephon spraying was repeated in December 2018 to induce flowering in the first ratoons, and harvesting was conducted in the summer of 2019. In the third year, second-generation ratoons were selected, but they exhibited poor vegetative growth, resulting in negligible fruit production.

Measurement of vegetative and reproductive traits

During flower emergence, various vegetative traits have been evaluated in pineapple plants. These included plant height (measured from the crown to the inflorescence), number of leaves per plant, leaf length, and the width of the largest leaf (leaf D) (Matos Viegas et al., 2014). At harvest, fruit characteristics were evaluated, including fresh weight (with and without crown), crown weight, crown weight percentage (calculated as crown weight divided by total fruit weight with crown multiplied by 100), fruit and crown length, fruit diameter (measured with Vernier calipers), number of reproductive organs, and fruit set percentage (proportion of plants bearing fruit per treatment). The yield was calculated based on the weight of the fruit (with and without crown) multiplied by the fruit set percentage, assuming 80,000 plants per hectare (Hung et al., 2024).

Statistical analysis

Data analysis was performed using SAS software (version 9.1.3). Mean comparisons were evaluated using Duncan's multiple range tests. A randomized complete block design (RCBD) was used in this experiment. Five treatments were evaluated, each with three replicates, with each replicate consisting of six pots.

RESULTS

Given the loss of all control plants, data analysis was conducted for the remaining four treatment groups. The results of these treatments are presented below.

Plant Height

The results revealed that the highest plant height (23.3 cm) was observed in plants grown in a cocopeat- perlite-sand mixture. This treatment did not differ significantly from the peat moss-perlite-sand mixture, but was significantly different from the other two treatments. The lowest plant height (21.5 cm) was recorded for plants grown in a peat moss-perlite mixture, which did not differ significantly from the cocopeat-perlite and peat moss-perlite-sand mixtures (Table 1).

Similarly, at the ratoon fruiting stage, the highest plant height (16.3 cm) was observed in plants grown in a cocopeat-perlite-sand mixture. This treatment did not differ significantly from the peat moss-perlite- sand mixture but was significantly different from the other two sand-free treatments. The peat moss- perlite and cocopeat-perlite treatments did not differ significantly and had plant heights of 13.4 cm and 14.3 cm, respectively (Table 2).

The results indicated an average decrease of 34.7% in ratoon plant height. The lowest reduction in plant height (30%) was observed in the cocopeat-perlite-sand treatment, whereas the highest reduction (38.6%) was observed in the cocopeat-perlite treatment.

Number of leaves

The results of this study revealed that the highest number of leaves (30) was observed in plants grown in a cocopeat-perlite-sand mixture. This treatment did not differ significantly from that of the peat moss- perlite-sand mixture. Additionally, the cocopeat-perlite and peat moss-perlite treatments, with 27 and 26 leaves, respectively, were grouped together without significant differences (Table 1).

Table 1. The effect of different growing media on plant height, number of leaves, leaf length and width, number of reproductive organs, and fruit weight with crown in the main fruit production stage.

Treatments	Plant height (cm)	Number of leaves	Leaf length (cm)	Leaf width (cm)	Number of reproductive organs	Fruit weight crown (g)
PP	21.5^{b*}	26.0^{b}	55.1^{d}	4.2^{c}	3.3^{c}	1095.0^{b}
PPS	22.6^{ab}	29.0^{a}	60.8^{b}	4.3^{b}	4.7^{b}	1168.7^{a}
CP	22.1^{b}	27.0^{b}	57.9^{c}	4.2^{c}	4.3^{b}	1125.3^{b}
CPS	23.3^{a}	30.0^{a}	63.7^{a}	4.5^{a}	5.3^{a}	1208.0^{a}

* Means with the same letters do not have significant differences based on Duncan's test at the 5% level.
PP: equal-volume mixture of peat moss and medium-grade perlite (2-5mm). PPS: equal-volume mixture of peat moss, perlite, and washed sand. CP: equal-volume mixture of cocopeat and perlite. CPS: equal-volume mixture of cocopeat, perlite, and washed sand.

Table 2. Effect of different growing media on plant height, number of leaves, leaf length and width, number of reproductive organs, and fruit weight with crown in the ratoon fruit production stage.

Treatments	Plant height (cm)	Number of leaves	Leaf length (cm)	Leaf width (cm)	Number of reproductive organs	Fruit weight crown (g)
PP	13.4^{b}	16.3^{d}	34.2^{d}	2.5^{b}	3.0^{b}	760.0^{c}
PPS	15.3^{a}	19.7^{b}	41.3^{b}	2.7^{b}	4.3^{a}	808.0^{ab}
CP	14.3^{b}	17.7^{c}	37.6^{c}	2.7^{b}	4.2^{a}	776.3^{bc}
CPS	16.3^{a}	21.3^{a}	45.2^{a}	3.0^{a}	4.6^{a}	851.0^{a}

* Means with the same letters do not have significant differences based on Duncan's test at the 5% level. PP: equal-volume mixture of peat moss and medium-grade perlite (2-5mm). PPS: equal-volume mixture of peat moss, perlite, and washed sand. CP: equal-volume mixture of cocopeat and perlite. CPS: equal-volume mixture of cocopeat, perlite, and washed sand.

At the ratoon fruiting stage, the highest number of leaves (21.3) was observed in the cocopeat-perlite-sand treatment. The peat moss-perlite-sand treatment ranked second with 19.7 leaves. The lowest number of leaves (16.3) was observed in the peat moss-perlite treatment, which differed significantly from the other treatments (Table 2).

On average, there was a 33.2% decrease in the number of leaves in ratoon plants compared with the main crop. The highest percentage decrease in leaf number (37.3%) was observed in the peat moss- perlite treatment, whereas the lowest decrease (29%) was observed in the cocopeat-perlite-sand treatment.

Leaf Length

The results of this study demonstrated that the type of growing medium had a significant impact on leaf length during the main fruiting stage. Plants grown in a cocopeat-perlite-sand mixture exhibited the longest leaf length (63.7 cm). The shortest leaf length (55.1 cm) was observed in plants grown in the peat moss-perlite mixture (Table 1).

During the ratoon fruiting stage, the type of growing medium also significantly influenced leaf length. The longest leaf length (45.2 cm) was found in plants grown in a cocopeat-perlite-sand mixture. The shortest leaf length (34.2 cm) was observed in plants grown in the peat moss-perlite mixture (Table 2).

On average, leaf length decreased by approximately 33.5% in ratoon plants compared with that in the main crop. The greatest reduction in leaf length (37.9%) was observed in plants grown in a peat moss- perlite mixture, whereas the least reduction (29%) was observed in plants grown in a cocopeat-perlite- sand mixture.

Leaf width

The results indicated a significant influence of growing medium type on leaf width during the main fruiting stage. Plants cultivated in a cocopeat-perlite-sand mixture exhibited the largest leaf width (4.5 cm), which was significantly different from that of the other treatments. The cocopeat-perlite and peat moss-perlite-sand mixtures were comparable, while the peat moss-perlite mixture displayed the smallest leaf width (4.2 cm), which was not significantly different from that of cocopeat-perlite (Table 1).

During ratoon fruiting, the growing medium continued to significantly affect leaf width. The cocopeat- perlite-sand mixture again yielded the widest leaves (3 cm), differing significantly from the other treatments. The remaining treatments exhibited similar leaf widths, ranging from 2.5 to 2.7 cm (Table 2).

On average, leaf width decreased by approximately 36.7% in ratoon plants compared with that in the main crop. The cocopeat-perlite-sand mixture demonstrated the smallest reduction in leaf width (33.3%), whereas the peat moss-perlite treatment exhibited the most pronounced decrease (40.5%).

Number of reproductive organs

The results of this study demonstrated that the type of growing medium significantly influenced the number of propagules in pineapple plants during the main fruiting stage. The highest number of propagules (5.3) was observed in plants cultivated in the cocopeat-perlite-sand mixture, which differed significantly from the other treatments. The peat moss-perlite-sand (4.7 propagules) and cocopeat-perlite (4.3 propagules) treatments were grouped together and showed no significant differences between them. The lowest number of propagules (3.3) was found in plants grown in peat moss-perlite, which differed significantly from the other treatments (Table 1).

During the ratoon fruiting stage, the type of growing medium significantly affected the number of propagules. The highest number of propagules (4.6) was observed in the cocopeat-perlite-sand mixture, which did not differ from the peat moss-perlite-sand or cocopeat-perlite treatments. The lowest number of propagules (3) was found in the peat moss-perlite treatment, which differed significantly from the other treatments (Table 2).

On average, the number of propagules in ratoon plants decreased by 8.3% compared with the main crop. This decrease ranged from 2.3% in the cocopeat-perlite treatment to 13.2% in the cocopeat-perlite- sand treatment.

Fruit weight with crown

The results of this study revealed that the type of growing medium significantly influenced the crown fruit weight of pineapple plants during the main fruiting stage. The highest crown fruit weight (1208 g) was observed in plants grown in a cocopeat-perlite-sand mixture, which did not significantly differ from plants grown in a peat moss-perlite-sand mixture (1168.7 g). The two treatments were then grouped together. Similarly, the cocopeat-perlite (1125.3 g) and peat moss-perlite (1095 g) treatments were grouped together and showed no significant difference between them (Table 1).

During the ratoon fruiting stage, the type of growing medium significantly affected crown fruit weight. The highest crown fruit weight (851 g) was observed in the cocopeat-perlite-sand mixture, which did not significantly differ from that of the peat moss-perlite-sand mixture (808 g). The lowest crown fruit weight (760 g) was observed in the peat moss-perlite treatment (Table 2).

Table 3. The effect of different growing media on fruit weight without crown, crown weight, crown weight percentage, fruit length with crown, fruit length without crown, and crown length in the main fruit production stage.

Treatments	Fruit weight without crown (g)	Crown weight (g)	Crown weight percentage	Fruit length with crown (cm)	Fruit length without crown (cm)	Crown length (cm)
PP	944.0d	206.0c	18.3 b	22.5d	11.3d	11.5c
PPS	981.0b	230.0a	18.5 b	25.1b	12.2b	12.3b
CP	956.7c	217.7b	18.4 b	24.1c	11.7c	11.8c
CPS	1009.0a	236.7a	18.7a	26.0a	12.8a	12.8a

* Means with the same letters do not have significant differences based on Duncan's test at the 5% level. PP: equal-volume mixture of peat moss and medium-grade perlite (2-5mm). PPS: equal-volume mixture of peat moss, perlite, and washed sand. CP: equal-volume mixture of cocopeat and perlite. CPS: equal-volume mixture of cocopeat, perlite, and washed sand.

On average, the crown fruit weight of ratoon plants decreased by 30.5% compared that with of the main crop. The variation in this decrease among the treatments was a maximum of 1.3%. The lowest decrease was observed in the cocopeat-perlite-sand treatment, whereas the highest decrease was observed in the peat moss-perlite-sand treatment.

Fruit weight without crown

The results of this study demonstrated that the type of growing medium significantly influenced the crownless fruit weight of pineapple plants during the main fruiting stage. The highest crownless fruit weight (1009 g) was observed in plants grown in the cocopeat-perlite-sand mixture, which differed significantly from the other treatments. The peat moss-perlite-sand mixture yielded a crownless fruit weight of 981 g, ranking second, and showing significant differences compared to other treatments. The lowest crownless fruit weight (944 g) was observed in the peat moss-perlite treatment, which differed significantly from the other treatments (Table 3).

During the ratoon fruiting stage, the type of growing medium significantly affected the crownless fruit weight. The highest crownless fruit weight (683 g) was observed in the cocopeat-perlite-sand mixture, which differed significantly from that of the other treatments. The peat moss-perlite-sand mixture yielded a crownless fruit weight of 647 g, and the lowest crownless fruit weight (602 g) was observed in the peat moss-perlite treatment. All treatments at the ratoon fruiting stage showed significant differences (Table 4).

On average, the crownless fruit weight of ratoon plants decreased by 34.3% compared with that of the main crop. The highest decrease in crownless fruit weight (36.2%) was observed in the peat moss-perlite treatment, whereas the lowest decrease (32.3%) was observed in the cocopeat-perlite-sand mixture.

Crown weight

The results of this study demonstrated that the type of growing medium significantly influenced the crown weight of pineapple plants during the main fruiting stage. The highest crown weight (236.7 g) was observed in plants grown in the cocopeat-perlite-sand mixture, which did not significantly differ from the peat moss-perlite-sand mixture. These two treatments were grouped together. The cocopeat-perlite treatment, with a crown weight of 217.7 g, was grouped separately and showed significant differences compared to the other treatments. The lowest crown weight (206 g) was observed in the peat moss-perlite treatment (Table 3).

During the ratoon fruiting stage, the type of growing medium also significantly affected the crown weight. The highest crown weight (164.7 g) was observed in the cocopeat-perlite-sand mixture, which differed significantly from the other treatments. The peat moss-perlite-sand mixture, with a crown weight of 148.3 g, ranked second and showed significant differences compared to the other treatments. The lowest crown weight (130.7 g) was observed in the peat moss-perlite treatment (Table 4).

On average, the crown weight of ratoon plants decreased by 34.7% compared to that of the main crop. The highest decrease in crown weight (36.6%) was observed in the peat moss-perlite treatment, whereas the lowest decrease (30.4%) was observed in the cocopeat-perlite-sand mixture.

Table 4. The effect of different growing media on fruit weight without crown, crown weight, crown weight percentage, fruit length with crown, fruit length without crown, and crown length in the ratoon fruit production stage.

Treatments	Fruit weight without crown (g)	Crown weight (g)	Crown weight percentage	Fruit length with crown (cm)	Fruit length without crown (cm)	Crown length (cm)
PP	602.0d	130.7d	18.4 b	13.6d	7.4d	7.5d
PPS	647.0b	148.3b	18.4 b	15.4b	8.3b	8.8b
CP	625.7c	138.7c	18.4 b	14.3c	7.9c	8.2c
CPS	683.0a	164.7a	18.7a	17.1a	9.1a	9.3a

* Means with the same letters do not have significant differences based on Duncan's test at the 5% level. PP: equal-volume mixture of peat moss and medium-grade perlite (2-5mm). PPS: equal-volume mixture of peat moss, perlite, and washed sand. CP: equal-volume mixture of cocopeat and perlite. CPS: equal-volume mixture of cocopeat, perlite, and washed sand.

Crown weight percentage

This study demonstrated a significant influence of the growing medium type on the percentage of crown weight to fruit weight in pineapple plants during the main fruiting stage. The cocopeat-perlite-sand mixture exhibited the highest percentage (18.7%), which differed significantly from the other treatments. The three other treatments, with percentages ranging from 18.3% to 18.5%, were statistically similar (Table 3).

During the ratoon fruiting stage, growing medium continued to significantly impact the percentage of crown weight to fruit weight. The cocopeat-perlite-sand mixture again yielded the highest percentage (18.7%), with other treatments showing no significant differences. All other treatments resulted in a crown weight percentage of 18.4% (Table 4).

Overall, the percentage of crown weight to fruit weight remained relatively consistent between the main crop and ratoon stages, averaging approximately 18.5%. Minor fluctuations were observed among the treatments, with a slight increase in the peat moss-perlite medium and a slight decrease in the cocopeat- perlite-sand mixture in ratoon plants.

Fruit length with crown

The results of this study indicated a significant influence of the growing medium on fruit length with the crown during the main fruiting stage. Each of the four growing medium treatments resulted in a distinct fruit length with a crown. The longest crown fruit (26 cm) was observed in the cocopeat-perlite-sand mixture. This was followed by peat moss-perlite-sand (25.1 cm) and cocopeat-sand (24.1 cm) mixtures. The shortest crown fruit (22.5 cm) was observed in the peat moss-perlite treatment (Table 3).

During the ratoon fruiting stage, the type of growing medium continued to significantly affect fruit length with the crown. The cocopeat-perlite-sand mixture again yielded the longest fruit length, with a crown (17.1 cm). Subsequently, peat moss-perlite-sand (15.4 cm) and cocopeat-sand (14.3 cm) mixtures were used. The shortest fruit length with the crown (13.6 cm) was observed in the peat moss-perlite treatment (Table 4).

On average, the fruit length with the crown of ratoon plants decreased by 38.3% compared that with of the main crop. The highest decrease (40.7%) was observed in the cocopeat-perlite treatment, whereas the lowest decrease (13.6%) was observed in the peat moss-perlite treatment.

Fruit length without crown

The results of this study demonstrated that the type of growing medium significantly influenced the crownless fruit length of pineapple plants during the main fruiting stage. Each of the four growing media treatments resulted in distinct crownless fruit lengths. The longest crownless fruit (12.8 cm) was observed in the cocopeat-perlite-sand mixture. This was followed by peat moss-perlite-sand (12.2 cm) and cocopeat-sand (11.7 cm) mixtures. The shortest crownless fruit (11.3 cm) was observed in the peat moss- perlite treatment (Table 3).

During the ratoon fruiting stage, the type of growing medium continued to significantly affect crownless fruit length. The cocopeat-perlite-sand mixture yielded the longest crownless fruit (9.1 cm), followed by the peat moss-perlite-sand (8.3 cm) and cocopeat-sand (7.9 cm) mixtures. The shortest crownless fruit (7.4 cm) was observed in the peat moss-perlite treatment (Table 4).

On average, the crownless fruit length of ratoon plants decreased by 32% compared with that of the main crop. The highest decrease (34.5%) was observed in the peat moss-perlite treatment, while the lowest decrease (28.9%) was found in the cocopeat-perlite-sand mixture.

Crown length

Statistical analysis revealed a significant impact of different growing media on crown length at both the primary and secondary fruiting stages. In the primary fruiting stage, the longest crown (12.8 cm) was observed in the treatments with cocopeat, perlite, and sand. Treatments with peat moss, perlite, and sand (12.3 cm), and cocopeat and sand (11.8 cm) followed, respectively, and were placed in the subsequent homogeneous statistical groups. The shortest crown (11.5 cm) was observed in the peat moss and perlite treatments (Table 3). In the secondary fruiting stage, the longest crown (9.3 cm) was observed in the treatment with cocopeat, perlite, and sand. Other treatments included peat moss with perlite and sand (8.8 cm) and cocopeat with sand (8.2 cm). Notably, crown length decreased by an average of 30.3% in the secondary fruiting stage. The highest decrease was observed in the treatment with peat moss and perlite (34.8%), whereas the lowest decrease was observed in the treatment with cocopeat, perlite, and sand (27.3%) (Table 4).

Fruit diameter

Statistical analysis revealed a significant impact of growing media on fruit diameter at both the primary and secondary fruiting stages. In the primary fruiting stage, the smallest fruit diameter (8.7 cm) was observed in the peat moss and perlite media. This medium, along with peat moss, perlite, sand, cocopeat, and sand (both 8.8 cm), was grouped into a homogeneous statistical group. However, cocopeat, perlite, and sand medium, with the largest fruit diameter (9.1 cm), were also included in this group, indicating no significant statistical difference between the three treatments (Table 5).

In the secondary fruiting stage, significant statistical differences were observed among the treatments. The cocopeat, perlite, and sand media exhibited the largest average fruit diameter (6.4 cm), whereas the smallest diameter (5.4 cm) was observed in the peat moss and perlite media (Table 6).

Table 5. The of different growing media on fruit diameter, fruit set, fruit yield with crown, and fruit yield without crown in the main fruit production stage.

Treatments	Fruit diameter (cm)	Fruit set (%)	Fruit yield with crown (g)	Fruit yield without crown (g)
PP	8.7[b]	86.7[a]	69547[c]	56789[c]
PPS	8.8 [ab]	100.0[a]	94293[a]	76880[a]
CP	8.8 ab	93.3[a]	81392[b]	66411[b]
CPS	9.1[a]	100.0a	101173a	82240[a]

* Means with the same letters do not have significant differences based on Duncan's test at the 5% level. PP: equal-volume mixture of peat moss and medium-grade perlite (2-5mm). PPS: equal-volume mixture of peat moss, perlite, and washed sand. CP: equal-volume mixture of cocopeat and perlite. CPS: equal-volume mixture of cocopeat, perlite, and washed sand.

Table 6. The of different growing media on fruit diameter, fruit set, fruit yield with crown, and fruit yield without crown in the ratoon fruit production stage.

Treatments	Fruit diameter (cm)	Fruit set (%)	Fruit yield with crown (g)	Fruit yield without crown (g)
PP	5.4[d]	66.7[b]	33163[c]	27061[c]
PPS	6.1[b]	80.0[ab]	51285[b]	41835[b]
CP	5.7[c]	73.3[ab]	41541[bc]	33893[bc]
CPS	6.4[a]	86.7[a]	62240[a]	50592[a]

* Means with the same letters do not have significant differences based on Duncan's test at the 5% level. PP: equal-volume mixture of peat moss and medium-grade perlite (2-5mm). PPS: equal-volume mixture of peat moss, perlite, and washed sand. CP: equal-volume mixture of cocopeat and perlite. CPS: equal-volume mixture of cocopeat, perlite, and washed sand.

Overall, the fruit diameter decreased by an average of 33.4% during the secondary fruiting stage. The greatest decrease (37.9%) was observed in the peat moss and perlite media, whereas the least decrease (29.7%) was observed in the cocopeat, perlite, and sand media.

Fruit set

Based on the results of this study, the type of growing medium did not have a significant effect on the fruit set percentage in the primary fruiting stage. All treatments were performed in a homogeneous statistical group. The highest fruit set percentage (100%) was observed in peat moss with perlite and sand and cocopeat with perlite and sand treatments, while the lowest percentage (86.7%) was observed in the peat moss with perlite treatment (Table 5).

In the secondary fruiting stage, significant differences were observed among the treatments. Peat moss with perlite and sand treatments had the highest fruit set percentage (86.7%). In contrast, peat moss with perlite and cocopeat with sand treatments had the lowest fruit set percentages (66.7%) and were placed in a homogeneous statistical group (Table 6).

Overall, the fruit set percentage decreased by an average of 19.5% during the secondary fruiting stage. The greatest decrease (23.1%) was observed in the peat moss with perlite treatment, whereas the lowest decrease (13.3%) was observed in the cocopeat with perlite and sand treatments.

Fruit yield with crown

Statistical analysis indicated that the type of growing medium had a significant impact on fruit yield per hectare during the initial production stage. As shown in Table 5, the treatments of cocopeat with perlite and sand and peat moss with perlite and sand yielded the highest fruit yields of 101,173 and 94,293 kg/ha, respectively, and there was no significant difference between them. The cocopeat with perlite treatment ranked next, with a yield of 81,392 kg/ha. The lowest yield (69,547 kg/ha) was observed in peat moss with perlite treatment, which differed significantly from the other treatments (Table 5).

In the ratooning fruit production stage, as shown in Table 6, the cocopeat with perlite and sand treatments had the highest yield of 62,240 kg/ha, which differed significantly from the other treatments. Peat moss with perlite and sand and cocopeat with perlite treatments were in the next group with yields of 51,285 and 41,541 kg/ha, respectively and there was no significant difference between them. Peat moss treated with perlite had the lowest yield (33,163 kg/ha) was observed in the peat moss with perlite treatment (Table 6).

Overall, the fruit yield decreased by an average of 46.4% during the ratooning stage. As shown in Tables 5 and 6, the highest yield reduction (52.3%) was observed in peat moss treated with perlite, and the lowest reduction.

Fruit yield without crown

Statistical analysis revealed that the type of growing medium had a significant impact on the yield. In the initial production stage, the combination of cocopeat with perlite and sand yielded the highest fruit yields (82, 240 and 76, 880 g/ha, respectively). However, the difference between the two combinations was not statistically significant. The cocopeat with perlite combination ranked next, with a yield of 66,411 kg/ha, while the lowest yield was observed in the peat moss with a perlite combination at 56,789 kg/ha (Table 5).

In the secondary (ratooning) production stage, the cocopeat with perlite and sand combination yielded the highest fruit yield at 50,592 kg/ha and showed a significant difference compared to other combinations.

Peat moss with perlite, sand, and cocopeat with perlite combinations had similar yields of 41,835 and 33,893 kg/ha, respectively (Table 6).

Overall, fruit yield decreased by an average of 46.4% in the secondary stage compared to that in the initial stage. The highest yield reduction (52.3%) was observed in the peat moss with perlite combination, whereas the lowest reduction (38.5%) was observed in the cocopeat with perlite and sand combination.

DISCUSSION

The findings of this study demonstrated that pineapple plants cultivated under shade conditions with drip irrigation exhibited superior vegetative and reproductive growth parameters during both the main crop and ratoon cycles. Specifically, these included increased plant height, leaf count, leaf dimensions, propagule number, fruit weight (including and excluding the crown), crown weight percentage, fruit length (including and excluding the crown), crown length, fruit diameter, fruit set, and total fruit yield when grown in a cocopeat-perlite-sand medium. The peat moss-perlite-sand medium yielded the second- best results.

Previous studies have consistently highlighted the significant impact of growing media on plant growth and development. In one study, the results indicated significant variations in the dry matter production of pineapple seedlings among the treatments. Compost-based media, particularly the 1:0 and 1:1 compost-to- topsoil ratios, demonstrated superior performance in terms of leaf and root dry weights, as well as total plant dry biomass. These findings underscore the importance of optimizing the composition of the growing media to enhance pineapple seedling growth and development (Ajema & Shewangizaw, 2021).

Another study confirmed the effect of growing media on the growth of young pineapple plants. Gebisa (2021) indicated significant differences among treatments with compost-based media, particularly 1:0 and 1:1ratios, promoting superior seedling growth. These findings suggest that compost-rich nursery media can effectively enhance pineapple seedling development and support subsequent field establishment and production (Gebisa, 2021). According to the research results of Lakho et al. (2023), the type of growing medium affects the adaptability of pineapple plantlets. Based on their results, while peat moss, a 1:1 bolhari-peat moss mixture, and river silt all supported high plantlet survival rates in the greenhouse (100%, 98.9%, and 95.1%, respectively), the survival rate in pure peat moss was significantly higher ($p < 0.05$).

A study examining the effects of various growing media on strawberry performance indicated that a bio- plus compost enriched with synthetic nutrients was the most effective substrate for enhancing strawberry growth and yield in a greenhouse environment (Madhavi et al., 2021). A study has shown that the type of growing medium affects the growth of basil plants. According to the results of this research, the cocopeat + perlite growing medium was the most effective in improving the physiological and phytochemical parameters of basil (Yonesi et al., 2025). Studies have shown that incorporating compounds like perlite or cocopeat into sand improves phytochemical traits (Agarwal et al., 2021).

Our results are consistent with those of Ilahi and Ahmad (2017), who showed that incorporating perlite into cocopeat enhanced the physical and hydraulic characteristics of the growth substrate. In line with our research, soilless substrates, such as sand, perlite, and cocopeat, outperform traditional soil in terms of Geranium oil production results in higher yields and enhanced oil quality (Rezaei Nejad & Ismaili, 2014). Our results, which showed that cocopeat had a positive effect, are consistent with a study that found that adding it to vermicompost had a positive effect on the growth of tomato plants (Erdal & Aktaş, 2025). Cocopeat's benefits for plant growth include its high water-holding capacity, antifungal properties, and significant phosphorus and potassium content. This contrasts with inorganic substrates such as pumice and sand, which generally have low nutrient levels (Chhetri et al., 2022)

Shade cultivation combined with drip irrigation has been shown to enhance various growth metrics of pineapple plants. This is consistent with the findings of Santos et al. (2020), who reported that partial shading improves pineapple growth and fruit quality. The observed increases in plant height, leaf count, and leaf dimensions under these conditions suggest an improved photosynthetic efficiency and overall plant vigor. These improvements in vegetative growth are crucial to the overall health and productivity of pineapple crops. Fruit characteristics were significantly improved, with larger fruit weights (including and excluding the crown), increased fruit length, and greater fruit diameter (Santos et al., 2020).

It's important to note that while these findings are promising; their applicability may vary depending on local climate conditions, soil types, and pineapple varieties. Farmers should consider conducting small- scale trials to determine the optimal combination of shade levels, irrigation schedules, and growing media for specific circumstances (Umi et al., 2020).

CONCLUSION

In summary, the addition of sand to growing media consisting of peat moss, perlite, cocopeat, and perlite when used in drip irrigation systems significantly enhanced plant growth and yield due to improved water-holding capacity and nutrient retention. At a planting density of 80,000 plants per hectare in greenhouses or shade houses, a total fruit yield of up to 101,173 g was obtained from the primary crop and 62,240 g from the ratoon crop.

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Data availability statement
All relevant data are included within the manuscript and its supplementary information files.

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