PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 11(sp4): 01–10
https://doi.org/10.14719/pst.5388

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RESEARCH ARTICLE

Cocopeat: An alternative to soil medium for propagation of papaya (*Carica papaya* L)

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OPEN ACCESS

ARTICLE HISTORY
Received: 30 September 2024
Accepted: 15 October 2024
Available online
Version 1.0 : 26 December 2024

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
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CITE THIS ARTICLE
Gowthami K, Vidhya D, Muthuvel I, Djanaguiraman M, Jagadeeswaran R. Cocopeat: An alternative to soil medium for propagation of papaya (*Carica papaya* L). Plant Science Today.2024;11(sp4):01-10. https:/doi.org/10.14719/pst.5388

Abstract

The present study aimed to standardize soilless media mixtures for papaya propagation, focusing on stability, sustainability and environmental impact. A trial was conducted in the winter and summer seasons during 2023-2024 at TNAU, Coimbatore, to evaluate the properties of cocopeat mixtures and optimize the cocopeat media mixture for papaya seedling production. The trial employed a factorial randomized complete block design with two factors [cocopeat media mixture (Factor-T) and papaya varieties (CO7 and TNAU Papaya CO8, as factor-V] and with four replicates. Each treatment contains different proportions of cocopeat, inorganic fertilizers, bio-inoculants, biofertilizers and oil cakes. Commercially available cocopeat and potting mixture were used as absolute control and control, respectively. The findings showed that T_2 (TNAU Mixture 2) consist of cocopeat (96.86%) + inorganic mixture (0.34%) + bioinoculant mixture (0.70%) + biofertilizer mixture (0.42%) + oil cakes mixture (0.42%) recorded increased seed vigour (96.86%), seedling survival (96.17%), seedling height (46.07 cm), leaf area/plant (28.50 cm^2), leaf chlorophyll (26.05 SPAD units) and total nutrient (N-1.89%, P-0.89%, K-3.47%). The treatment T_4 (commercially available cocopeat alone) had the highest germination (97.90%) and was on par with T_2. Among the variety, V_2 outperformed V_1. In the treatment (T) and variety (V) interaction, the $T_2 \times V_2$ combination promoted significant seedling growth at the nursery. Cocopeat media mixtures showed good physical properties, like bulk density(g/cc), particle density (g/cc), porosity (%) and water holding capacity (%), promoting better seedling growth. The trial revealed that the treatment T_2 is recommended as the best alternative soilless medium for papaya propagation.

Keywords

bio-inoculants; cocopeat; inorganic fertilizers; oilcakes; papaya

Introduction

Papaya fruits are unique for their rich nutritive value and abundance of phytochemicals, and their cultivation continues to expand across tropical and subtropical regions worldwide (1). Papaya is commercially propagated from seeds, an effective and traditional method (2). Several biotic and abiotic factors impact the yield and quality of papaya fruit (3). Therefore, high-quality planting material is crucial for papaya production, as it directly impacts both the quality and quantity of harvest (4). The health and quality of nursery seedlings will depend on factors such as seed quality, growing media, seed treatments and environmental conditions. Among these factors, the quality of seedling production is primarily determined by the traits of the growing medium and the nutrients provided to it (4,5). It also supports the plant by anchoring its root structure. Soil-based natural growing substrates are commonly used for plant propagation because they are affordable and effective at promoting quick crop germination in the tropics. Traditional soil-based media typically consists of red earth, sand and topsoil. However, using such natural soil for nursery media preparation can negatively impact soil conservation, leading to soil erosion, loss of fertile land, decreased soil fertility, habitat disruption and increased land degradation. Soil is also a non-renewable resource (6). Additionally, the soil may be the harbour for disease and pest inoculums. Further, it will complicate the health of nursery plants (7). Environmental and agricultural studies have well-documented several negative impacts of using natural soil for nursery media preparation on soil conservation (8).

Nowadays, with more land being converted for agricultural, industrial and urban purposes, the availability of land to sustainably source these natural growing substrates is diminishing (9). This again reduces the supply of natural media and makes it challenging to access them in an environmentally responsible manner, highlighting the need for sustainable alternatives (10). As per the United Nations projections, the global population will increase from 7.5 billion to 9.7 billion by 2050 (11). Feeding the growing population will increase pressure on cultivable land. Increasing productivity or adding 4% more land is needed. However, expanding land is impossible (12). In this scenario, simple, low-cost soilless production systems, especially for nurseries, may be part of the solution to the problems created by the lack of fertile natural substrate. Each year, India requires around 200 million certified quality planting materials for crops propagated through cloning. This demand again requires a large amount of potting mixture. Traditionally, plant propagation practices have utilized varying proportions of red earth, sand and farmyard manure (FYM) as a potting mixture. However, the availability of these inputs faces several limitations. Soil-based media often harbour soil-borne pathogens, increasing the risk of soil-borne diseases in plants. The excavation of river sand and red earth for domestic use is restricted due to legal and environmental concerns. At the same time, high-quality FYM has become scarce in recent years due to urbanization.

Additionally, peat, a traditional organic material commonly used in potting mixtures to enhance physical properties in horticultural propagation, is considered an endangered natural resource, raising sustainability concerns. Soilless media have gained prominence to mitigate these challenges, with cocopeat emerging as a widely favoured alternative. It is renewable, naturally pathogen-free and possesses excellent physical properties, making it an ideal potting mixture for modern propagation systems. Given these concerns, efforts have been made to standardize soilless media mixtures for papaya nurseries. Since it is a seed-propagated crop and the cost of seeds is high for the ruling varieties, soilless media could help reduce the cost of seedling production while ensuring the production of high-quality seedlings for the main field. However, soilless media have gained popularity in recent years for their versatility and effectiveness (13). Soilless media are emerging as the future of plant cultivation, defined as any sterile growth medium free from soil (14). These soilless media combine organic and mineral components, including peat moss, vermiculite, perlite, coconut coir, composted bark and other materials (15). These materials are frequently used with fertilizers to deliver all the nutrients to plants. In recent years, a renewable and eco-friendly cocopeat has been proposed as an alternative to horticultural sphagnum peat. Its advantages include being renewable, eco-friendly and industrial waste (16,17). The shift towards soilless media offers a viable alternative to traditional growing mediums and addresses the sustainability of natural mediums like peat moss. Among several soilless media, coco coir is an excellent substrate for cultivating crops due to its adaptability and resemblance to peat moss (18). To mitigate peatland exploitation, there is a rising focus on replacing sphagnum peat-based media with alternatives like coco pith, especially in tropical areas with abundant coconut palms.

Coir fibre is a worldwide dispersed substrate, also referred to as coir pith, coir meal or cocopeat. It is obtained from the coconut fruit mesocarps' dense outer layer, or mesocarp (*Cocos nucifera* L.). After the ageing process of raw material, the commercial coconut coir dust contains a mixture of 75-80% coconut coir dust (size: <1 mm) and 20-25% of coconut short fibres with a particle size of 1-3 mm (19). Coco pith is used in plant propagation, mulching, soil improvement and disease management, contributing to a renewable and environmentally friendly system. Utilizing a combination of organic and mineral components, along with cocopeat, can provide a balanced environment for plant propagation while minimizing the ecological impact associated with the depletion of natural resources (20-24). In soil scarcity and climate uncertainty, soilless plant propagation can provide a sustainable approach that reduces waste and enhances plant productivity efficiently (25). With this background, this study sought to assess the effects of several cocopeat-based soilless media to speed up the sexual propagation of papaya. Ultimately, this research provides valuable insights for propagators and researchers working with alternative media for fruit crop propagation and has the potential to impact ecosystem conservation positively.

Materials and Methods

The trials were conducted at College Orchard, Tamil Nadu Agricultural University, Coimbatore (India) under nursery in a factorial randomized complete block design (FCRD) with two factors and four replicates. Factor - T was a different combination of cocopeat media mixture, and Factor- V was a papaya variety *viz.,* CO7 as (V_1) and TNAU Papaya CO_8 as (V_2) were taken for the study. The chosen papaya varieties had different genetic backgrounds, growth characteristics and propagation responses. Additionally, they are among the most popular papaya varieties. The sex for CO7 is gynodioecious and TNAU Papaya CO8 is dioecious. The sex forms of the varieties exhibit differential growth behaviours both in the nursery and the main field. Hence, the study was conducted to support soilless media mixtures, irrespective of the varieties used. Each soilless media mixture contains different proportions of cocopeat, inorganic fertilizers (urea, mono ammonium phosphate, calcium nitrate and rock phosphate), The bio-inoculants *viz., Trichoderma viride* (28 x 10^8CFU/gram)*, Bacillus subtilis* (2 x 10^8 CFU /gram) *Azospirillum* (1x10^9CFU/gram) Phosphate Solubilizing bacteria-

PSB (1x10[9]CFU/gram), Vesicular Arbuscular Mycorrhizae-VAM (8-10 IP/gram) and *Purpureocillium lilacinum* (1 x 10[8] CFU/gram) and oil cakes includes neem cake, groundnut cake and castor cake.

Various combinations of soilless cocopeat mixtures (T_1, T_2 and T_3) were prepared and compared using raw cocopeat. The treatment mixture T_4 was made from six-month-aged commercially available cocopeat. The initial physical and chemical properties of mixtures were measured (Table 1) using standard protocol. The initial electrical conductivity (EC) of freshly extracted cocopeat (T_1, T_2 and T_3) was 4.64 (dS/m), which was reduced to an ideal range between 0.28 to 0.41 (dS/m) through repeated washing with water. Still, in the case of T_4, the initial EC was 0.27 (dS/m). Each treatment contains different proportions of cocopeat, inorganic fertilizers, bio-inoculants, biofertilizers and oil cakes. The details of treatments (T) were T_1:TNAU Mixture 1 - [cocopeat (98.43%) + inorganic mixture (0.8%) + bioinoculant mixture (0.35%) + biofertilizer mixture (0.21%) + oil cakes mixture (0.21%)], T_2:TNAU Mixture 2 -[cocopeat (96.86%) + inorganic mixture (0.34%) + bioinoculant mixture (0.70%) + biofertilizer mixture (0.42%) + oil cakes mixture (0.42%)], T_3:TNAU Mixture 3 - (Cocopeat (99.78%) + Inorganic mixture (0.15%) + Bioinoculant mixture (0.07%)], T_4: commercially available cocopeat alone used as an absolute control and T_5:Potting mixture (2:1:1 Red Earth: Soil: Farmyard manure) as a control.

Observations on seed and seedling biometrics such as seed germination (%), Seed vigour (%), Seedling survival (%), Seedling height (cm), Leaf area per plant (cm^2) and chlorophyll (SPAD unit) were measured at 45th days after sowing (DAS). The medias' physical properties were analyzed from each treatment and its respective replications. The collected media samples were air-dried in the shade and stored in plastic bags for further analysis. The medias' physical properties, such as bulk density (g/cc), particle density (g/cc) and porosity (%), were assessed by standard methods and water holding capacity (%) by standard methods at 45th DAS (26,27). The total nitrogen present in the leaves was determined by using diacid extraction. Using 15 ml of diacid mixture (2 parts of sulphuric acid: 5 parts of perchloric acid) to the 0.5 g of leaf sample and subjected for digestion and nitrogen content was estimated by the Microkjeldhal method described and expressed in percent (28). The total phosphorus was determined using the vanadomolybdate phosphoric yellow colourimetric method and reported as a percentage (29). The total potassium was measured through the flame photometry standard method and expressed as a percentage (29). The pooled data of different attributes obtained from the trials were subjected to ANOVA using the R package at $p< 0.05$ to determine the treatment effects. The least-square difference (LSD) test was used to compare means.

Results and Discussion

Effect of treatment on seed and seedling growth attributes

In the present experiment, the soilless cocopeat mixture significantly affected the final germination percent of papaya seeds at $p < 0.05$. The response of papaya seeds to a soilless cocopeat mixture varied according to the properties of each media. The highest germination percent was recorded in T_4 (97.90%), followed by T_2(95.30%) and T_1(94.66%), while T_3 (90.12%) had the lowest (Table 2). The findings consistently showed a significant effect of soilless cocopeat mixture on seed vigour, seedling survival percent, seedling height, leaf area per plant, leaf chlorophyll and total nitrogen (N), phosphorus (P) and potassium (K) percent, at $p < 0.05$ (Table 2-4). Notably, significant variations in T_2 were observed for increased seed vigour (96.86%), seedling survival (96.17%), seedling height (46.07 cm), leaf area per plant (28.50 cm^2), leaf chlorophyll (26.05 SPAD units) and total N, P and K (1.89%, 0.89% and 3.47%) respectively. Among the treatments, T_4 recorded the reduced seed vigour (77.67%), seedling survival (43.84%), seedling height (18.81 cm), leaf area per plant (10.70 cm^2), leaf chlorophyll (14.65 SPAD units) and total N, P and K of 0.78%, 0.56% and 1.17% respectively at 45th DAS (Table 2-4). The treatment with potting mixture as control reported seed vigour (83.54%), seedling survival (73.66%), seedling height (36.24 cm), leaf area per plant (15.75 cm^2), leaf chlorophyll (19.10 SPAD units) and total N, P and K (1.78%, 0.75% and 2.36%), which was significantly superior over T_4.

The results obtained from the study were aligned in papaya and mango, utilizing cocopeat as a growing medium, which had the highest seed germination percentage compared to soil (20,21). Cocopeat-based media significantly improved seed germination compared to soil (T_5), likely due to its porous texture, which enhanced aeration and ensured a steady oxygen supply (30). It could retain moisture while maintaining good drainage, which created an optimal germination environment,

Table 1. Physical and chemical properties of different media mixtures before sowing

Parameters	T_1	T_2	T_3	T_4	T_5	SE.d	(P< 0.05)
Bulk density (g/cc)	0.42^c	0.42^c	0.43b^c	0.44^b	1.36^a	0.01	**0.02**
Particle density (g/cc)	0.62^b	0.63^b	0.65^b	0.63^b	2.51^a	0.03	**0.06**
Porosity (%)	32.26^c	33.33^b	33.85^b	30.16^d	46.67^a	0.43	**0.88**
EC (dS/m)	0.28^{cd}	0.27^d	0.29^c	0.41^b	0.57^a	0.01	**0.02**
pH	6.02^d	6.00^d	6.25^c	6.49^b	7.50^a	0.08	**0.16**
Nitrogen (%)	1.33^a	1.34^a	1.31^a	1.33^a	0.24^b	0.02	**0.04**
Phosphorus (%)	1.05^a	1.07^a	1.00^b	0.93^c	0.13^d	0.02	**0.04**
Potassium (%)	1.65^a	1.68^a	1.60^b	1.01^c	0.31^d	0.02	**0.04**
Organic Carbon (%)	40.20^b	39.60^b	41.50^a	30.98^c	5.40^d	0.59	**1.20**
Carbon: Nitrogen ratio	30.00:1^b	29.80:1^b	30.70:1^a	23.29:1^c	22.50:1^d	0.21	**0.43**
Proportion of particle size (%)							
2 mm sieve	91.00^c	92.98^{bc}	93.58^{abc}	94.84^{ab}	95.98^a	1.35	**2.75**
1 mm sieve	75.30^b	79.36^a	72.82^c	69.52^d	79.28^a	0.31	**0.63**
0.5 mm sieve	62.70^b	62.16^b	62.88^b	69.48^a	63.82^b	1.09	**2.22**

Table 2. Effect of soilless media on papaya seed and seedling attributes at 45th days after sowing

Treatments	Germination (%)			Seed vigour (%)			Seedling survival (%)		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1	92.41^{bc}	96.92^{a}	**94.66^{b}**	94.69^{a}	95.88^{a}	**95.28^{a}**	92.36^{b}	92.37^{b}	**92.36^{b}**
T_2	93.16^{b}	97.45^{a}	**95.30^{b}**	96.82^{a}	96.91^{a}	**96.86^{a}**	95.79^{a}	96.55^{a}	**96.17^{a}**
T_3	87.17^{d}	93.07^{b}	**90.12^{c}**	90.78^{b}	91.90^{b}	**91.34^{b}**	71.48^{d}	73.22^{cd}	**72.35^{c}**
T_4	97.75^{a}	98.05^{a}	**97.90^{a}**	76.45^{d}	78.89^{d}	**77.67^{d}**	43.56^{e}	44.13^{e}	**43.84^{d}**
T_5	89.46^{cd}	95.10^{ab}	**92.28^{c}**	83.39^{c}	83.70^{c}	**83.54^{c}**	72.09^{d}	75.24^{c}	**73.66^{c}**
Mean	**91.99^{b}**	**96.12^{a}**		**88.42^{a}**	**89.46^{a}**		**75.05^{b}**	**76.30^{a}**	
	T	V	T x V	T	V	T x V	T	V	T x V
SE.d	1.11	0.70	1.57	0.91	0.58	1.29	0.72	0.46	1.02
(P< 0.05)	**2.262**	**1.430**	**3.199**	**1.863**	**NS**	**NS**	**1.477**	**0.934**	**NS**

Note: T_1: TNAU Mixture 1 - [Cocopeat (98.43%) + Inorganic mixture (0.8%) + Bioinoculant mixture (0.35%) + Biofertilizer mixture (0.21%) + Oil cakes mixture (0.21%)], T_2: TNAU Mixture 2 - [Cocopeat (96.86%) + Inorganic mixture (0.34%) + Bioinoculant mixture (0.70%) + Biofertilizer mixture (0.42%) + Oil cakes mixture (0.42%)], T_3: TNAU Mixture 3 - [Cocopeat (99.78%) + Inorganic mixture (0.15%) + Bioinoculant mixture (0.07%)], T_4: commercially available cocopeat alone used as an absolute control and T_5: Potting mixture (2:1:1 Red Earth: Soil: Farmyard manure) as a control. V_1- CO7; V_2-TNAU Papaya CO8; T - Treatments; V- Variety; T×V: interaction effect of treatment and variety; [a,b,c,...] Number followed by the same letters within a column indicates no significant difference based on the least square difference (LSD) at p.0.05%

Table 3. Effect of soilless media mixture on papaya seedling height (cm), Leaf area per plant (cm^2) and Chlorophyll (SPAD Unit) at 45th days after sowing

Treatments	Seedling height (cm)			Leaf area per plant (cm^2)			Chlorophyll (SPAD Unit)		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1	39.29^{c}	41.88^{b}	**40.58^{b}**	21.35^{d}	25.76^{b}	**23.55^{b}**	24.55^{b}	26.85^{a}	**25.70^{a}**
T_2	45.57^{a}	46.57^{a}	**46.07^{a}**	24.65^{c}	32.35^{a}	**28.50^{a}**	24.85^{b}	27.25^{a}	**26.05^{a}**
T_3	37.88^{d}	38.75^{cd}	**38.31^{c}**	19.95^{e}	21.77^{d}	**20.86^{c}**	20.35^{d}	21.65^{c}	**21.00^{b}**
T_4	17.98^{g}	19.64^{f}	**18.81^{e}**	10.15^{i}	11.25^{h}	**10.70^{e}**	14.45^{f}	14.85^{f}	**14.65^{d}**
T_5	36.27^{e}	36.21^{e}	**36.24^{d}**	13.15^{g}	18.36^{f}	**15.75^{d}**	18.95^{e}	19.25^{e}	**19.10^{c}**
Mean	**35.39^{b}**	**36.61^{a}**		**17.85^{b}**	**21.90^{a}**		**20.63^{b}**	**21.97^{a}**	
	T	V	T x V	T	V	T x V	T	V	T x V
SE.d	0.38	0.24	0.53	0.26	0.16	0.36	0.22	0.14	0.31
(P< 0.05)	**0.771**	**0.488**	**1.091**	**0.524**	**0.333**	**0.743**	**0.447**	**0.284**	**0.632**

especially in T_4. Here, the balance of moisture and air around the seeds supported enzymatic activity, accelerated metabolite synthesis and promoted faster seedling development by aiding seed coat breakdown (31). Additionally, cocopeats' cation exchange capacity facilitated nutrient retention and efficient gas exchange during germination (32). The results obtained from the study aligned with previous research (22,23).

In this investigation, T_2 was provided with optimum aeration and porosity, which promoted healthy seedling growth, height and vigour (23). Additionally, there was a consistent increase in seed germination initially and later, at 45th DAS, a consistent decrease in seedling growth in T_4 was observed. This might be due to low ionic concentration and poor media aeration. Low salt concentrations and electrical conductivity (EC) were essential to avoid osmotic stress and enhance water uptake for growth (33). In T_4, the recorded lowest survival percentage was likely due to the fine particle size of the media and high water retention, which might have created oxygen deficiency and increased the incidence of damping-off in papaya seedlings (34).

Notably, enhanced growth of T_2 was linked with better root development and nutrient availability (24). In this experiment, the treatments T_2 and T_1 were enriched with inorganic fertilizers, bio-inoculants, biofertilizers and oilcake, which might have facilitated improved root surface area, water absorption and gas exchange, ultimately enhancing photosynthesis (35). The biofertilizers and bioinoculants in T_2 might have promoted root growth through phytohormone synthesis, root branching and improved water and nutrient uptake (36). The slow nutrient-releasing nature of the oilcake mixture available in T_2 might have further supported seedling growth, improving height, leaf expansion, chlorophyll and total nutrient availability (37). The increased leaf chlorophyll in T_2 led to enhanced photosynthesis and energy production, which might have furled plant growth and metabolic processes (38). Additionally, the increased total nitrogen, phosphorus and potassium levels in T_2 and the media might have supported enhanced photosynthesis, root development and stress resistance. The inferior performance of T_4 was likely due to poor aeration, media compaction and limited nutrient availability, which hindered root growth and nutrient uptake (22,34).

Effect of variety on seed and seedling growth attributes

In this investigation, the tested papaya varieties (V_1 and V_2) showed statistically significant differences ($p < 0.05$) in their seed and seedling growth attributes (Fig.1 & plate. 1A, 1B, 1C & 1D). The variety, V_2 exhibited the highest germination (96.12%), seedling survival (76.30%), seedling height (36.61 cm), leaf area per plant (21.90 cm^2), leaf chlorophyll (21.97 SPAD units) and total N (1.65%), P (0.78%) and K (2.50%) at 45th DAS. In contrast, V_1 exhibited the lowest seed germination (91.99%), seed vigour (88.42%), seedling survival (75.05%), seedling height (35.39 cm), leaf area per plant (17.85 cm^2), leaf chlorophyll (20.63 SPAD units) and total N, P and K (1.61%, 0.75%, 2.32%) respectively at 45th DAS (Table 4. & Fig. 1).

The V_1 used in the trial was CO_7, which was gynodioecious and the other was V_2 (TNAU Papaya CO8), which was a dioecious nature. The significant variation in seed germination, seedling growth and leaf total nutrients found among the dioecious and gynodioecious varieties might have been due to their reproductive strategies, genetic potential and genetic diversity

Table 4. Effect of soilless media mixture on total leaf content nitrogen (%), phosphorus (%) and potassium (%) of papaya seedlings at 45th days after sowing

Treatments	Nitrogen (%)			Phosphorus (%)			Potassium (%)		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1	1.84^{cde}	1.88^{ab}	**1.86^{b}**	0.82^{d}	0.85^{c}	**0.83^{b}**	2.48^{e}	2.66^{c}	**2.57^{b}**
T_2	1.88^{abc}	1.91^{a}	**1.89^{a}**	0.88^{b}	0.90^{a}	**0.89^{a}**	3.33^{b}	3.61^{a}	**3.47^{a}**
T_3	1.83^{de}	1.85^{bcd}	**1.84^{b}**	0.77^{e}	0.80^{d}	**0.78^{c}**	2.38^{f}	2.58^{d}	**2.48^{c}**
T_4	0.76^{h}	0.80^{g}	**0.78^{d}**	0.54^{g}	0.58^{f}	**0.56^{e}**	1.13^{i}	1.21^{h}	**1.17^{e}**
T_5	1.77^{f}	1.80^{ef}	**1.78^{c}**	0.75^{e}	0.76^{e}	**0.75^{d}**	2.29^{g}	2.44^{ef}	**2.36^{d}**
Mean	**1.61^{b}**	**1.65^{a}**		**0.75^{b}**	**0.78^{a}**		**2.32^{b}**	**2.50^{a}**	
	T	V	T x V	T	V	T x V	T	V	T x V
SE.d	0.016	0.010	0.022	0.007	0.005	0.010	0.026	0.017	0.037
(P< 0.05)	**0.033**	**0.020**	**NS**	**0.014**	**0.010**	**NS**	**0.053**	**0.035**	**0.075**

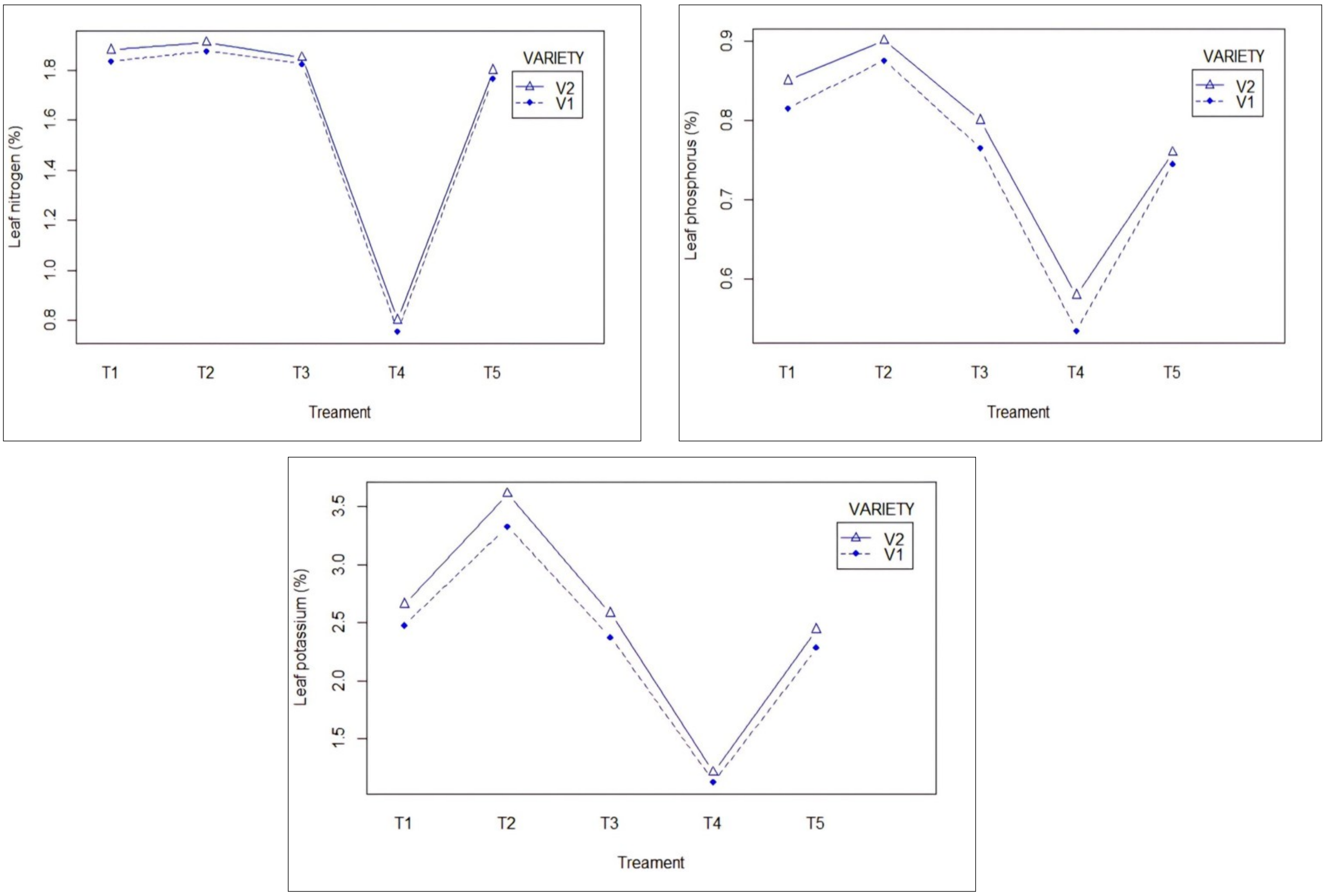

Fig. 1. Effect of soilless media and varieties interaction on total nitrogen, phosphorus and potassium (%) of papaya at 45th Days after sowing**.**

Note: T_1: TNAU Mixture 1 - [Cocopeat (98.43%) + Inorganic mixture (0.8%) + Bioinoculant mixture (0.35%) + Biofertilizer mixture (0.21%) + Oil cakes mixture (0.21%)], T_2: TNAU Mixture 2 - [Cocopeat (96.86%) + Inorganic mixture (0.34%) + Bioinoculant mixture (0.70%) + Biofertilizer mixture (0.42%) + Oil cakes mixture (0.42%)], T_3: TNAU Mixture 3 - [Cocopeat (99.78%) + Inorganic mixture (0.15%) + Bioinoculant mixture (0.07%)], T_4: commercially available cocopeat alone used as an absolute control and T_5:Potting mixture (2:1:1 Red Earth: Soil: Farmyard manure) as a control. V_1- CO7; V_2-TNAU Papaya CO8; T - Treatments; V- Variety; TxV: interaction effect of treatment and variety; [a,b,c,...] A number followed by the same letters within a column indicates no significant difference based on the least square difference (LSD) at p.0.05%

Plate 1. Influence of soilless media mixtures on papaya seedlings growth at 45th days after sowing.

Note: T_1: TNAU Mixture 1 - [Cocopeat (98.43%) + Inorganic mixture (0.8%) + Bioinoculant mixture (0.35%) + Biofertilizer mixture (0.21%) + Oil cakes mixture (0.21%)], T_2: TNAU Mixture 2 - [Cocopeat (96.86%) + Inorganic mixture (0.34%) + Bioinoculant mixture (0.70%) + Biofertilizer mixture (0.42%) + Oil cakes mixture (0.42%)], T_3: TNAU Mixture 3 - [Cocopeat (99.78%) + Inorganic mixture (0.15%) + Bioinoculant mixture (0.07%)], T_4: commercially available cocopeat alone used as an absolute control and T_5:Potting mixture (2:1:1 Red Earth: Soil: Farmyard manure) as a control. V_1- CO7; V_2-TNAU Papaya CO8; T - Treatments ;V- Variety; T×V: interaction effect of treatment and variety.

(35,38). However, the specific effect on seed and seedling growth would have depended on whether the seeds arose from self- or cross-pollination (39). Expression of inbreeding depression effects in gynodioecious variety (V_1) might be the reason for the reduced response of V_1 over V_2 for seed germination, seedling growth and leaf total nutrient status of the seedlings (40). At the seedling stage, dioecious and gynodioecious plants often showed notable differences in nutrient uptake due to their unique reproductive strategies and physiological responses (41, 42). The result was aligned with (43).

Interaction effect on seed and seedling growth attributes

The interaction between treatments and varieties significantly influenced seedling growth attributes (Fig.1A-1C). The combination of $T_2 \times V_2$ yielded the highest seedling survival (96.55%), seedling height (46.57 cm), leaf area per plant (32.35 cm^2), chlorophyll (27.25 SPAD units) and total nutrients N, P and K (1.91%, 0.90% and 3.61%) respectively at 45th DAS. These enhanced growth attributes of $T_2 \times V_2$ were attributed to adequate and balanced nutrient supply, favourable media properties and favourable environmental conditions (36,43), which supported the seedlings' growth regardless of variety. The more significant difference in these treatments indicated that the varietys' genetic response becomes more evident under suboptimal conditions, consistent with previous research on plant growth response to nutrient stress (44). Notably, the $T_2 \times V_2$ combinations significantly increased the photosynthetic activity attributed to the highest leaf chlorophyll content, facilitating more effective light absorption. This relationship highlighted the crucial role of chlorophyll in promoting photosynthesis, as noted by (39). Improved photosynthetic efficiency translated to higher energy production, directly benefiting seedling growth. The $T_2 \times V_2$ combination yielded the highest total leaf N, P and K content, indicating optimal nutrient availability and uptake. This likely enhanced key metabolic processes such as protein synthesis, energy transfer and water regulation, essential for plant growth and development (44). V_2 superior genetic efficiency in nutrient use, particularly nitrogen for chlorophyll formation and photosynthesis, may have contributed to this outcome (36).

In contrast, the highest seed germination was registered by $T_4 \times V_2$ (98.05%) interaction and was on par with $T_4 \times V_1$ (97.75%), $T_2 \times V_2$ (97.45%) and $T_1 \times V_2$ (96.92%) while the lowest germination was recorded in $T_3 \times V_1$ (87.17%). The genetics of variety (V_2) and T_4 environment might positively enhance the germination speed. The interaction between soilless cocopeat mixture and variety on seed vigour (%) and seedling survival (%) was insignificant. Additionally, $T_4 \times V_1$ reported with the lowest seedling height (17.98 cm), leaf area per plant (10.15 cm^2), chlorophyll (14.45 SPAD units) and total K (1.13%) respectively (Fig. 1A-1C). The $T_4 \times V_1$ combination exhibited the lowest photosynthetic activity and chlorophyll content. This deficiency was linked to suboptimal growth conditions, such as poor aeration and inadequate nutrient availability in the media, which are known to hinder chlorophyll production and photosynthesis (36). Such conditions led to stunted growth and reduced plant vigour, consistent with findings from previous studies (45). Additionally, the lowest leaf nutrient status indicates a suboptimal nutrient regime. Low nitrogen is likely to limit chlorophyll production, while insufficient phosphorus impaired root development and low potassium affected water regulation and stress tolerance (36). These deficiencies suggest the need for nutrient adjustments in underperforming combinations.

Physical properties of soilless media mixtures

The analysis of variance indicated that bulk density, particle density, porosity and water holding capacity of the soilless cocopeat mixtures differed (Fig. 2) significantly among the treatments ($p < 0.05$) at 45th DAS. In the treatment, T_5 registered with the highest bulk density of 1.38g/cc, while T_1 (0.34g/cc) and T_2 (0.34g/cc) had the lowest. T_5 (2.04 g/cc) reported the maximum particle density and the minimum in T_4 (0.52 g/cc). Meanwhile, T_2 (45.97%) recorded the highest porosity, whereas T_4 (22.12%) exhibited the lowest. The maximum water holding capacity was observed in T_4 (80.24%), while the lowest was in T_5 (59.00%). Considering the varieties and the interaction between treatment and varieties, non-significant differences were observed in the physical properties of the media (Table 5 & Fig.2A -2D).

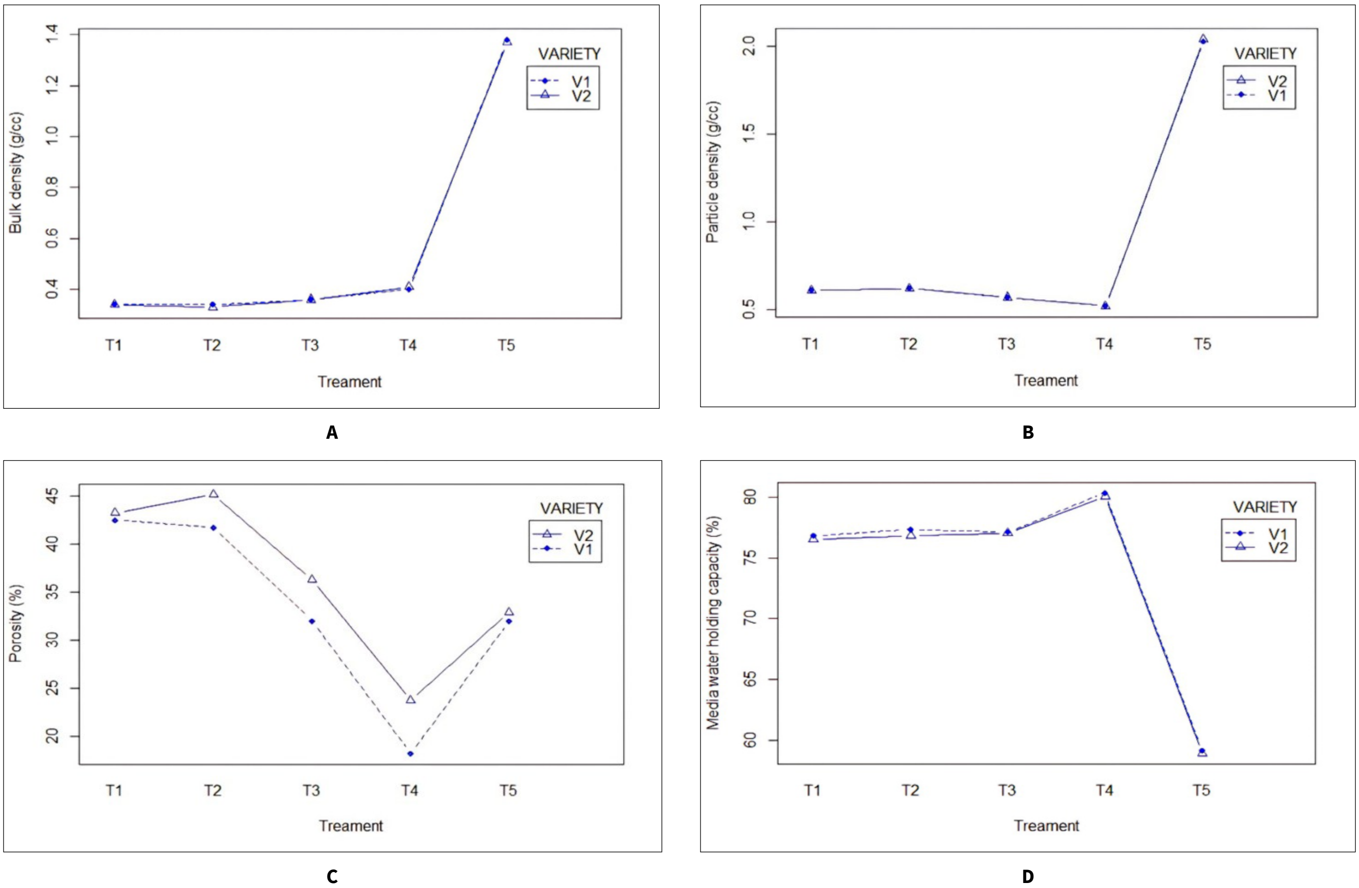

Fig. 2. Effect of soilless media and varieties interaction on physical properties of soilless media mixtures at 45th days after sowing.

Table 5: Bulk density (g/cc), Particle density (g/cc), porosity (%) and Water holding capacity (%) of soilless media mixtures at 45th days after sowing

Treatments	Bulk density (g/cc)			Particle density (g/cc)			Porosity (%)			Water holding capacity (%)		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1	0.34^{d}	0.34^{d}	**0.34^{d}**	0.61^{b}	0.61^{b}	**0.61^{b}**	44.26^{b}	44.26^{b}	**44.26^{b}**	76.86^{b}	76.54^{b}	**76.70^{b}**
T_2	0.34^{d}	0.33^{d}	**0.34^{d}**	0.62^{b}	0.62^{b}	**0.62^{b}**	45.16^{b}	46.77^{a}	**45.97^{a}**	77.37^{b}	76.86^{b}	**77.12^{b}**
T_3	0.36^{c}	0.36^{c}	**0.36^{c}**	0.57^{c}	0.57^{c}	**0.57^{c}**	36.84^{c}	36.84^{c}	**36.84^{c}**	77.14^{b}	77.05^{b}	**77.10^{b}**
T_4	0.40^{b}	0.41^{b}	**0.41^{b}**	0.52^{d}	0.52^{d}	**0.52^{d}**	23.08^{e}	21.15^{f}	**22.12^{e}**	80.36^{a}	80.11^{a}	**80.24^{a}**
T_5	1.38^{a}	1.37^{a}	**1.38^{a}**	2.03^{a}	2.04^{a}	**2.04^{a}**	32.02^{d}	32.84^{d}	**32.43^{d}**	59.10^{c}	58.90^{c}	**59.00^{c}**
Mean	**0.56^{a}**	**0.56^{a}**		**0.87^{a}**	**0.87^{a}**		**36.27^{a}**	**36.38^{a}**		**74.17^{a}**	**73.89^{a}**	
	T	V	T x V	T	V	T x V	T	V	T x V	T	V	T x V
SE.d	0.005	0.003	0.008	0.009	0.006	0.013	0.343	0.217	0.485	0.657	0.417	0.931
(P< 0.05)	**0.010**	**NS**	**NS**	**0.018**	**NS**	**NS**	**0.700**	**NS**	**NS**	**1.34**	**NS**	**NS**

In general, the desirable physical properties of cocopeat should be with a bulk density of less than 0.4 g/cc, particle density of 0.63 gm/cc and total porosity of 75.81% (46). In this experiment, the variance analysis indicated that the soilless cocopeat mixtures' bulk density, particle density and porosity differed significantly among the treatments ($p < 0.05$) and fell under desirable ranges. Among the treatments, T_5, a soil-based potting mixture, exhibited the highest bulk density, particle density and optimum porosity. Meanwhile, among the soilless cocopeat mixtures, T_1 and T_2 were registered with reduced bulk and particle densities and an increased porosity percentage over T_4. When observing the particle size proportion among the soilless mixtures, treatment T_4 exhibited the highest rate of short fibres of less than 2mm in size and fine particles less than 0.5mm, which might have contributed to enhanced bulk density and particle density. The researchers were noticed the similar results (47, 48). When considering the porosity percentage of the media, T_4 exhibited the lowest porosity due to compact packing of fine cocopeat particles less than 0.5mm. Hence, the reduction in total pore space of T_4 significantly affected plant growth due to decreased pore space, which limited oxygen transport and root penetration in media, enhancing water retention (49). When comparing the particle size proportion of T_4 with T_2, the percentage of fine particles was minimal, indicating its coarse nature and enhanced porosity. High macro-pores, characterized by numerous large pores, ensured adequate drainage and promoted proper aeration in the media mixture (50).

Conclusion

The study concluded that soilless cocopeat mixture, T_2 (TNAU Mixture 2), consisted of cocopeat (96.86%) + inorganic mixture (0.34%) + bioinoculant mixture (0.70%) + biofertilizer mixture (0.42%) + oil cakes mixture (0.42%) was found to be the most effective media mixture to enhancing the growth and performance of papaya seedlings, outperforming the other treatments across key growth parameters. Among the varieties, TNAU Papaya CO 8 (V_2) demonstrated superior seed germination and growth performance compared to CO7 (V_1). Furthermore, the interaction T_2 and V_2 yielded the most outstanding results in terms of seedling growth in the nursery, favouring conditions for papaya seedling development.

Acknowledgements

The authors acknowledge the support of the Tamil Nadu Agricultural University, Coimbatore to allow to conduct the research and provide technical guidance. The ICAR, New Delhi and Ethereal DNA Pvt. Ltd, Hyderabad to provide research assistantship during 2023-2024.

Authors' contributions

All the authors contributed equally to conceptualizing the work, interpretation, analysis, writing, reviewing and editing of the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used ChatGPT to use to improve language and readability, with caution. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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