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*Research Article*

# Scanning Electron Microscopy (SEM) and Fourier Transform Infrared Spectroscopy (FTIR) analysis of raw and composted coir pith as soilless media

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**Abstract**
Coir pith, an abundant agro-industrial by-product of coconut processing, is increasingly explored as a sustainable alternative to peat-based substrates in soilless cultivation. However, its direct application is constrained by a high carbon-to-nitrogen (C: N) ratio, the complexity of lignocellulose, and potential phytotoxicity. Composting is commonly employed to improve its physico-chemical properties and enhance its usability as a growing medium. The present study aimed to evaluate changes in chemical composition, elemental characteristics, and functional group properties of raw and composted coir pith using advanced analytical techniques. Composting was carried out for 30 days using a layered method with microbial inoculation (*Pleurotus sajor-caju*-based formulation) and urea supplementation. Results indicated a reduction in C:N ratio from 70.7:1 to 32.7:1 and a decrease in total organic carbon from 59.39% to 30.80%. Nutrient contents increased, with total nitrogen rising from 0.84% to 0.94%, phosphorus from 0.02% to 0.86%, and potassium from 1.84% to 1.96%. SEM analysis revealed structural degradation and altered pore architecture, while EDX showed a reduction in carbon (from 71% to 60%) and an increase in oxygen (from 25% to 32%). FTIR analysis indicated qualitative changes in functional groups associated with lignocellulosic components. These findings demonstrate that composting induces significant physicochemical and structural modifications in coir pith, suggesting its potential suitability as a soilless substrate. However, the contribution of external nitrogen inputs and the lack of plant-based validation highlight the need for further investigation.

**Keywords:** Coir pith, Fourier Transform Infrared Spectroscopy, Scanning Electron Microscopy with energy dispersive X-ray Spectroscopy, Soilless substrate

## INTRODUCTION

Coir is a completely natural fibre derived from coconut husks. It shares similar physical properties and a similar chemical composition with wood fibres. Coconut fibres are densely packed with a non-fibrous, lightweight, and cushioned cork-like substance called coir pith, also referred to as coir dust, which makes up 50–70% of the coconut husk. Coir pith, a flexible material that holds coir fibres together within the husk, is commonly used as a growing medium in seedling production, as bedding material, in potting mixes, and in landscaping and hydroponic cultivation of flowers, vegetables, trees, and shrubs. Additionally, it serves as a composting material, container gardening substrate and a casing layer for mushroom cultivation. Currently, coir pith stands out as an eco-friendly and sustainable alternative to sphagnum peat moss, rock wool and sawdust. For hydroponic or container-grown plant development, products made from coir pith provide excellent root development (CCRI, 2016). The carbon-to-nitrogen (C: N) ratio of coir pith typically ranges from 58:1 to 112:1. When it comes to lignin and cellulose content, fully matured coconut husks generally yield coir pith with higher lignin content and lower water-soluble salts compared to younger husks.

Coir pith is commonly chosen as a nursery substrate for seed germination and seedling development. However, in its raw form, coir pith has been associated with lower germination rates, reduced growth, and compromised physiological parameters. These limitations are primarily attributed to its wide C:N ratio and the presence of phenolic compounds, which may induce phytotoxic effects such as chlorosis and growth inhibition (Anbarasu and Gurusamy, 2021).

The agricultural performance of biological soilless substrates is largely governed by the composition, transformation, and stability of their organic fractions. Recent studies highlight that the degree of lignocellulosic degradation, humification, and carbon stabilization significantly influences nutrient dynamics and microbial activity in soilless systems (Alam *et al.,* 2024; Satheesh *et al.,* 2024). The organic components of such substrates enhance water retention, cation exchange capacity (CEC), and nutrient buffering, while also supporting beneficial microbial communities (Machado *et al.,* 2022; Kafle *et al.,* 2024). However, improvements in these properties do not necessarily translate directly into enhanced plant growth unless validated through controlled biological experiments.

In recent years, increasing emphasis has been placed on valorizing agro-industrial residues, such as coir pith, as sustainable alternatives to peat-based substrates, driven by environmental concerns and circular bioeconomy principles (Alam *et al.,* 2024; Satheesh *et al.,* 2024). Consequently, detailed characterization of organic fractions is essential to assess substrate maturity, stability, and the reduction of phytotoxicity. Nevertheless, many composting approaches involve both biological inoculants and chemical amendments (e.g., nitrogen fertilizers), which can confound the interpretation of substrate improvements.

Fourier Transform Infrared (FTIR) spectroscopy has emerged as a reliable, non-destructive analytical tool for identifying functional groups and monitoring biochemical transformations in organic substrates. It is widely used to assess lignocellulosic changes and functional group evolution associated with compost maturity (Elakiya and Arulmozhiselvan, 2021; Ganesan and Nallathambi, 2022). However, FTIR primarily provides qualitative information and cannot independently quantify the degradation of lignin, cellulose, or hemicellulose. Similarly, Scanning Electron Microscopy (SEM) coupled with Energy-dispersive X-ray (EDX) analysis provides insights into the surface morphology, porosity, and elemental composition of substrates. Recent studies indicate that composting can modify the microstructure and elemental distribution of coir pith (Kafle *et al.,* 2024; Saurabh *et al.,* 2025). However, such structural observations do not directly confirm improvements in aeration or plant growth performance without supporting physical or biological measurements.

Although the use of *Pleurotus sajor-caju* for coir pith composting has been previously reported, there remains a need for integrated characterization under combined biological and chemical treatment conditions using multiple analytical techniques. Therefore, the present study was undertaken to evaluate the chemical properties, elemental composition, and functional group characteristics of raw and composted coir pith using advanced analytical methods. It is important to note that the study does not isolate the independent effects of microbial inoculation and nitrogen supplementation, a limitation acknowledged by the authors. Accordingly, the primary objective of this study was to assess whether the physicochemical properties of composted coir pith indicate its potential suitability as a soilless substrate, rather than to establish its effectiveness for crop growth directly.

## MATERIALS AND METHODS

### Study location

The study was conducted at the Department of Agronomy, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai - 625104 Tamil Nadu, India (9˚54'N latitude and 78˚54'E longitude).

### Analysis of chemical composition

The pH of the substrates was determined using a pH meter (ORION 230A, USA), with a measurement range of −2 to 19.99 and an accuracy of ±0.01. Electrical conductivity (EC) was measured using an EC meter (Model ORION 105, USA; range: 0 to 199.99 dS $m^{-1}$ ± 0.01).

Total Organic Carbon (TOC) content was estimated by the dry-ignition method at 540°C for 4 hours. Total nitrogen was determined using the Kjeldahl method (Bremner and Mulvaney, 1982). Phosphorus content was analyzed using the colorimetric method (Murphy and Riley, 1962), and potassium was determined using atomic absorption spectroscopy. The carbon-to-nitrogen (C:N) ratio was calculated from measured TOC and total nitrogen values (C:N = TOC/Total N), and all values were verified for mathematical consistency.

### Scanning electron microscopy (SEM) and Energy dispersive X-ray (EDX) analysis

The surface morphology and elemental composition of raw and composted coir pith were analyzed using

Scanning Electron Microscopy (SEM) coupled with Energy Dispersive X-ray (EDX). A FEI Quanta 250 SEM operating at 30 kV was used for imaging. Samples were ground to pass through a 0.5 mm sieve and sputter-coated with a thin gold layer prior to analysis. The instrument, equipped with a field emission gun (FEG), provided imaging with a resolution of 1.4 nm. EDX spectra were collected from three independent regions of each sample, and mean values were reported to account for sample heterogeneity. EDX results are considered semi-quantitative.

**Fourier transform infrared (FTIR) analysis**

Fourier Transform Infrared spectroscopy was performed using a JASCO FTIR-6800 spectrometer equipped with a pyroelectric triglycine sulfate (TGS) detector. Samples were prepared using the solid-film technique, and spectra were recorded over 4000–350 $cm^{-1}$ at a resolution of 4 $cm^{-1}$ using Spectra Manager™ Cross-Platform Software. FTIR analysis was used for qualitative identification of functional groups, and interpretations were based on relative changes in peak intensity. Quantitative estimation of lignin, cellulose, or hemicellulose degradation was not inferred from FTIR data alone.

**Composted coir pith preparation**

Raw coir pith was composted using a commercial bio-formulation, PITH PLUS (developed by Central Coir Research Institute and its containing lignocellulolytic fungi including *Pleurotus sajor-caju*). Urea was applied as an external nitrogen source during composting; therefore, changes in nitrogen content and C:N ratio reflect the combined influence of biological decomposition and chemical nitrogen addition.

**Composting process**

Coir pith composting was carried out using a layered (sandwich) method. Initially, 100 kg of raw coir pith was evenly spread over a 5 m × 3 m area. A packet of Pith Plus (400 g) was uniformly applied over this layer. This was followed by the addition of another 100 kg of coir pith, over which 1 kg of urea was evenly applied. A third layer of 100 kg coir pith was then added.

This layering process was repeated until the desired heap size was reached. Moisture content was maintained daily by sprinkling water (approximately 25 buckets per heap) to ensure optimal microbial activity. The composting process was continued for 30 days.

For large-scale composting, the process was scaled proportionally using one ton of coir pith, 2 kg of Pith Plus, and 5 kg of urea, while maintaining approximately 200% moisture content throughout the decomposition period.

During composting, heat generation was observed within the heap. To regulate temperature and enhance aeration, perforated PVC pipes were inserted vertically from the top to the bottom of the heap (Anbarasu *et al.,* 2024).

No control treatment (e.g., coir pith with urea alone or microbial inoculant alone) was included; therefore, the independent effects of biological and chemical treatments could not be distinguished.

**Statistical analysis**

A Completely Randomized Design (CRD) was employed, and all observations were based on three independent replicates. In addition to mean and standard deviation (± SD), statistical comparisons between raw and composted coir pith were performed using Student's t-test at a significance level of $p < 0.05$. Exact p-values were used to determine statistical significance (Gomez and Gomez,1984). Statistical analysis was carried out using IBM SPSS Statistics version 25.0.

## RESULTS AND DISCUSSION

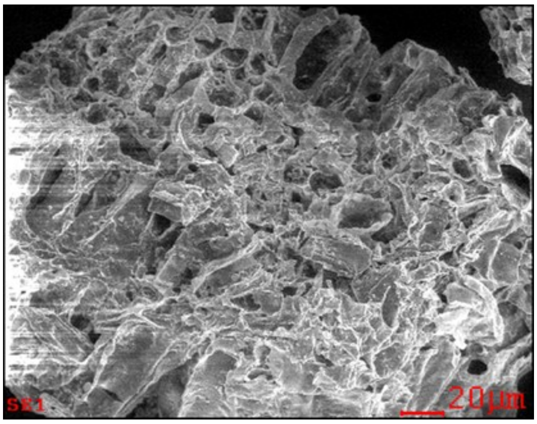
**Chemical composition**

The pH and electrical conductivity (EC) of a growing medium are critical parameters that influence nutrient availability and substrate behaviour. In the present study, raw coir pith exhibited a pH of 6.23 and EC of 5.02 dS $m^{-1}$, whereas composted coir pith showed slightly lower values (Table 1). These observations are consistent with recent findings indicating that composting coir pith generally stabilizes pH and reduces soluble salts through microbial transformation and leaching (Jana and Boxi, 2020).

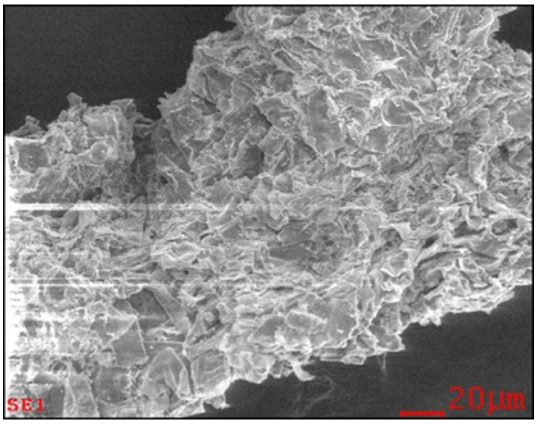
**Table 1.** The chemical properties of raw coir pith and compost coir pith

| Parameters | Coir pith | Compost coir pith |
|---|---|---|
| pH | 6.23±0.030 | 6.00±0.035 |
| EC ($dSm^{-1}$) | 5.02±0.076 | 4.80±0.036 |
| TOC (%) | 59.39±1.391 | 30.80±0.240 |
| Total N (%) | 0.84±0.014 | 0.94±0.012 |
| C: N ratio | 70:70±0.042 | 32:76±0.017 |
| Total P2O5 (%) | 0.02±0.0001 | 0.86±0.017 |
| Total K2O (%) | 1.84±0.022 | 1.96±0.005 |

*Values are expressed as mean ± SD of three replications for each parameter.



Coir pith (a)



Composted coir pith (b)

**Fig 1.** *Scanning electron microscopic view of raw coir pith (a) and composted coir pith (b) images demonstrate that composting caused significant structural breakdown of coir pith, characterized by fibre disintegration, pore deformation, and collapse of the lignocellulosic matrix*

Composted coir pith recorded higher total nitrogen (0.94%), phosphorus (0.86%), and potassium (1.96%) compared to raw coir pith. However, these increases must be interpreted cautiously, as urea was added during composting, directly contributing to nitrogen enrichment and influencing nutrient dynamics. Recent studies confirm that nutrient enrichment in coir pith compost often results from a combination of external inputs and concentration effects arising from carbon loss during decomposition, rather than microbial synthesis alone (Bera *et al.,* 2025).

The corrected carbon-to-nitrogen (C: N) ratio decreased from approximately 70.7:1 in raw coir pith to 32.7:1 in composted coir pith, indicating enhanced decomposition within 30 days. High initial C:N ratios and lignin content are well-recognized limitations of raw coir pith, which restrict its direct agricultural use due to nitrogen immobilization and phytotoxic effects (Bera *et al.,* 2025). The observed reduction in the C:N ratio reflects both microbial carbon degradation and external nitrogen addition; therefore, it cannot be attributed solely to fungal activity. Recent studies further highlight that compost maturity and reduced phytotoxicity are strongly linked to the breakdown of phenolic compounds and improved humification during composting (Satheesh *et al.,* 2024; Kafle *et al.,* 2024). Although these changes suggest improved substrate stability, no plant-based assays were conducted in this study; hence, direct implications for crop growth remain unverified.

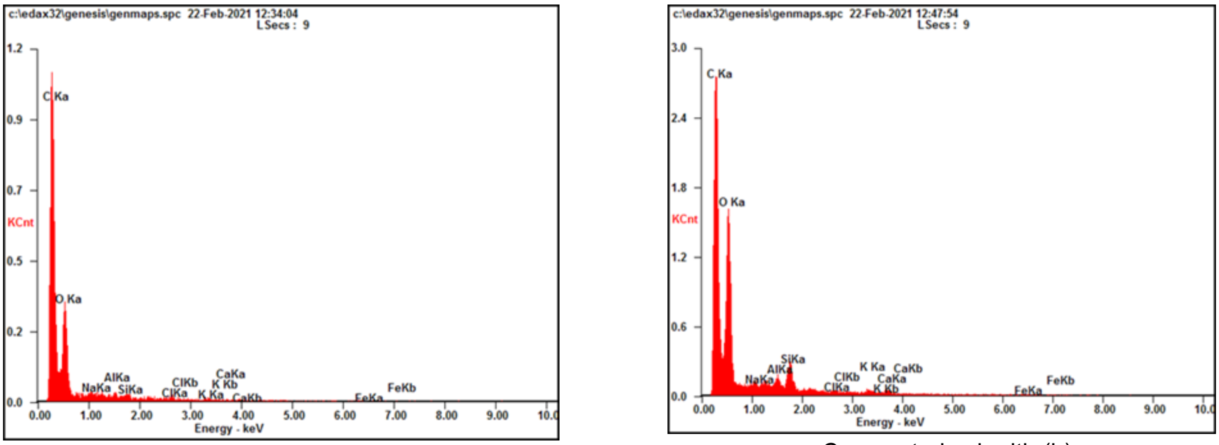
**Scanning electron microscopy (SEM) analysis**

Scanning Electron Microscopy (SEM) analysis revealed distinct morphological differences between raw and composted coir pith. Raw coir pith exhibited tightly packed, tubular, and fibrous structures with defined pores, indicating an intact lignocellulosic matrix (Fig. 1a). In contrast, composted coir pith showed disrupted cell walls, irregular pore distribution, and partially collapsed or contracted pore structures (Fig. 1b), indicating structural degradation. Recent studies employing SEM analysis of treated coir pith have similarly reported structural disintegration, fibre fragmentation, and alterations in pore architecture following biological or chemical processing (Bioresource Technology Reports, 2023).

These findings indicate that composting alters the structural integrity of coir pith rather than uniformly increasing porosity. Therefore, assumptions regarding improved aeration based solely on SEM observations are not directly supported. While structural changes may

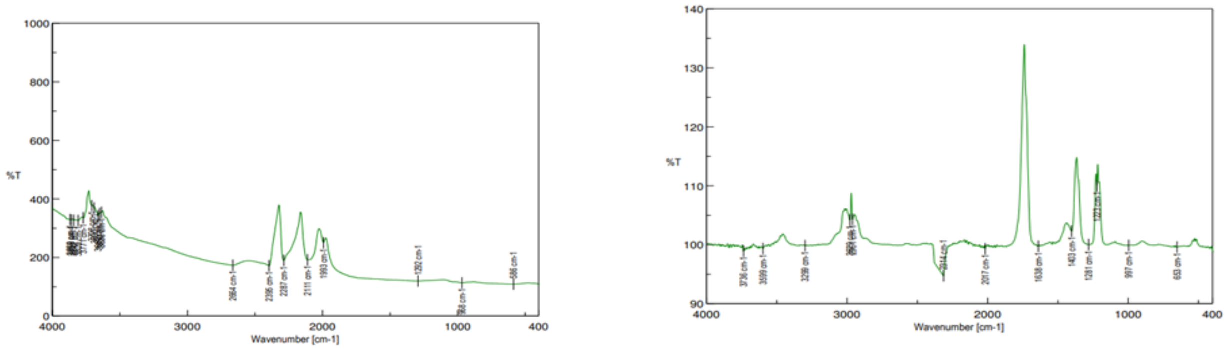
**Table 2.** Elements of coir pith and composted coir pith by EDX

| Element | Elements of coir pith | | Elements of composted coir pith | |
|---|---|---|---|---|
| | Wt% | At% | Wt% | At% |
| CK | 71.06 | 77.86 | 59.82 | 68.53 |
| OK | 24.80 | 20.40 | 32.87 | 28.27 |
| NaK | 00.60 | 00.34 | 00.30 | 00.18 |
| AlK | 00.56 | 00.27 | 00.38 | 00.45 |
| SiK | 00.67 | 00.31 | 03.03 | 01.48 |
| ClK | 00.90 | 00.33 | 00.33 | 00.13 |
| KK | 01.02 | 00.34 | 01.20 | 00.42 |
| CaK | 00.40 | 00.13 | 01.58 | 00.54 |




Coir pith (a) Composted coir pith (b)

**Fig 2.** *SEM - EDX spectrum of raw coir pith (a) and composted coir pith (b)*




Coir pith (a) Composted coir pith (b)

**Fig 3.** *Fourier transform infrared (FTIR) spectrum of raw coir pith (a) and composted coir pith (b)*

influence water retention and root interactions, their direct effects on plant growth and aeration require further validation through physical and biological measurements.

**Energy dispersive X-ray (EDX) analysis**

EDX analysis revealed that raw coir pith consisted predominantly of carbon (71%) and oxygen (25%), with trace elements (<1%) such as Na, Al, Si, Cl, Cu, and K. In composted coir pith, the carbon content decreased to approximately 60%, while the oxygen content increased to around 32%. This trend is consistent with organic matter mineralization, in which carbon is released as $CO_2$ and oxygen-rich functional groups become relatively more prominent (Fig. 2 and Table 2). Similar reductions in carbon content and increases in oxygen proportion have been reported in recent coir pith composting and biomass degradation studies, indicating progressive oxidation and humification processes (Satheesh *et al.,* 2024; Bera *et al.,* 2025).

It is important to note that EDX provides semi-quantitative elemental composition, and the reported values represent localized measurements rather than absolute bulk composition. Therefore, the results should be interpreted cautiously. Although lignocellulosic degradation by fungal activity may contribute to these changes, the experimental design does not allow separation of microbial and chemical (urea) effects.

**Fourier transform infrared (FTIR) analysis of coir pith**

FTIR spectroscopy revealed characteristic absorption bands corresponding to lignin, cellulose, and hemicellulose in raw coir pith, particularly in the 3200–3600 $cm^{-1}$ region associated with O–H stretching vibrations. In composted coir pith, changes in peak intensity and reduction in certain functional group signals were observed, including hydroxyl and aromatic structures. Peaks corresponding to O–H stretching (~3299 $cm^{-1}$) and C–H stretching (2967, 2314, and 2017 $cm^{-1}$) were identified (Fig 3 and Table 3).

Recent studies have reported similar FTIR spectral modifications during coir pith treatment, reflecting alterations in lignocellulosic structure and functional group composition due to degradation processes (Bioresource Technology Reports, 2023). However, FTIR is a qualitative analytical technique, and changes in peak intensity cannot be used to quantitatively confirm reductions in lignin, cellulose, or hemicellulose. The observed functional group modifications may influence surface reactivity and adsorption properties, which are important for nutrient retention and cation exchange in soilless substrates. Recent studies also emphasize that such functional transformations are associated with improved substrate maturity and re-

**Table 3**. Characteristic peaks assignment of raw coir pith and composted coir pith

| Peaks in $cm^{-1}$ | Functional group | Coir pith peaks in $cm^{-1}$ | Composted coir pith peaks in $cm^{-1}$ |
|---|---|---|---|
| 3420 | Hydroxyl (O-H) groups in phenolic and aliphatic structure | -3000 | 3299 |
| 2930 | C-H Stretching in aromatic methoxyl groups, Aliphatic C-H Stretching group | 2664, 2395, 2287, 2111 | 2967, 2314, 2017 |
| 1730 | Carbonyl stretching group (C=O) in the lignin structure | | |
| 1620 | C=C stretching is associated with aromatic skeletal vibrations, C=O, C-O, OH groups, and Water is associated with lignin. | | 1638 |
| 1550 | Conjugated hydrogen-bonded carboxyl group | | |
| 1510 | C=C stretching, Lignin content | 1993 | 1403 |
| 1450 | Methoxy group (0-CH3) of lignin structure, Carboxylic acid group | 1292 | |
| 1370 | 0-H deformation arising from the phenolic group | | 1281 |
| 1250 | 0-H deformation arising from the phenolic group, C-OH stretching | | 1223 |
| 1060 | C-O stretching in the secondary alcohol, C-C, stretching and C-OH bending in polysaccharides | 968, 586 | 997 |

duced phytotoxicity (Satheesh *et al.,* 2024). Nevertheless, no direct measurements of cation exchange capacity or plant growth performance were conducted in this study; therefore, these functional implications remain inferential.

The combined physicochemical and spectroscopic analyses indicated that composting led to a reduction in the C:N ratio, a decrease in carbon content with a corresponding relative increase in oxygen, structural modifications in the coir matrix, and changes in functional group composition. These transformations collectively reflect the progression of organic matter stabilisation and decomposition. The changes are generally associated with improved compost maturity, reduced phytotoxicity, and enhanced suitability of coir pith for agricultural applications; however, these implications remain indicative and require validation through biological assays under crop conditions (Satheesh *et al.,* 2024; Bera *et al.,* 2025; Waman *et al.,* 2025). However, due to the confounding influence of urea addition and the absence of plant-based validation, these findings should be interpreted as indicative of potential substrate improvement rather than conclusive evidence of enhanced agronomic performance.

## Conclusion

The present study demonstrated that composting of coir pith using microbial inoculation and nitrogen supplementation resulted in measurable changes in its physicochemical and structural properties. The composted coir pith exhibited a reduced C:N ratio, decreased carbon content, and alterations in functional group composition, indicating progression toward substrate stabilisation. SEM analysis revealed structural disintegration of the coir matrix, while EDX and FTIR analyses confirmed modifications in elemental composition and functional groups, respectively. However, the observed improvements in nutrient content and C:N ratio cannot be attributed solely to biological decomposition, as urea addition contributed to nitrogen enrichment and influenced overall nutrient dynamics. Furthermore, FTIR and EDX analyses provided qualitative and semi-quantitative insights, and therefore do not allow precise quantification of lignocellulosic degradation or elemental changes. Although the physicochemical characteristics of composted coir pith suggested its potential suitability as a growing medium, this study did not include plant-based assays to validate its effects on seed germination, crop growth, or yield. Therefore, conclusions regarding its agronomic performance should be interpreted with caution and considered indicative rather than definitive. Overall, the findings indicate that composting modifies coir pith properties that may enhance its suitability for soilless cultivation systems. Future research should focus on controlled experiments to distinguish the individual effects of microbial inoculation and chemical amendments, as well as comprehensive plant growth trials under nursery and protected cultivation conditions to substantiate its practical applicability.

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### Conflict of interest

The authors declare that they have no conflict of interest.

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