

Research Article

Characterization of substrates of growing media by Fourier transform infrared (FT-IR) spectroscopy for containerized crop production

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Abstract

Growing media used in soilless culture systems are those solid substrates, which alone or in mixtures can guarantee better plant growth conditions similar to agricultural soil in one or many aspects. This study was aimed to characterize lignocellulosic organic substances predominant in most available and effective organic substrates viz., coir pith and dhaincha (*Sesbania aculeata*) powder and compost maturity in vermicompost based on the presence of functional groups by Fourier transform infrared (FT-IR) spectroscopy. The dominant downward peaks noted at 3300-3500 cm^{-1} in coir pith and dhaincha indicate vibration of hydroxyl (OH-) stretch in cellulose structure and presence of alcohols and phenols. Peaks at 2925-2850 cm^{-1} found prominently in coirpith would be indicative of vibration of C-H bonds showing aliphatic degradation of cellulose, hemicelluloses, lipids, fats, etc. Particularly in dhaincha, vibration at 1733.32 cm^{-1} would be due to C=O stretch associated with an unconjugated ketone, carbonyl and ester groups. In vermicompost, peak value around 1549.85 cm^{-1} indicates C=C aromatic structure formed during mineralization of protein, cellulose, and hemicelluloses showing compost maturity. In the present study, FT-IR analysis of organic lignocellulosic substrates confirmed the occurrence of lignin, hemicellulose and cellulose, which are the main characteristics of natural fibers with high water holding and cation exchange capacity. Presence of alcoholic and carboxylic groups indicated stages of compost maturity and stability. Therefore, these renewable and environmentally sustainable lignocellulosic organic materials could be recognized as ideal soilless substrates for preparing grow media for containerized crop production and also recycling organic wastes in an environmentally friendly manner.

Keywords: Coir pith, Dhaincha, FT-IR, Growing media, Vermicompost

INTRODUCTION

Soilless culture systems are increasingly being adopted as a major technological component in the modern greenhouse industry which developed rapidly during the last 30-40 years (Gruda *et al.*, 2018) to sustain profitable agriculture globally over recent decades (Schmilewski, 2009). The term "soilless culture" in general refers to any method of growing plants without the use of soil as a rooting medium (Savvas, 2003; Gruda *et al.*, 2016a). The soilless culture can be done by cultivation of crops on porous growing media which creates a matrix retaining both air and water at suitable ratios for plant growth. The main innovations that turned soilless culture into the leading cultivation technology in modern

greenhouses include the development of suitable growing media (GM) with optimal physical, hydraulic, and chemical properties, such as rockwool and coir, and the advances put forth in plant nutrition and irrigation via modern fertigation equipment and automation technologies (Savvas and Gruda, 2018).

Growing media are solid substrates, which alone or in mixtures can guarantee better plant growth conditions similar to agricultural soil in one or many aspects (Gruda *et al.*, 2013). The independence from the soil as a rooting medium in soilless culture facilitates optimizing both physical and chemical characteristics in the crop root environment and more efficient pathogen control eliminating application of soil fumigation. Therefore, higher yields at a reasonable production cost with minimal use of pesticides

and high product quality can be attained (Gruda *et al.*, 2018).

The selection of an appropriate substrate composition based on technical and economic feasibility is an important aspect of research and key to success in any soil-less production system (Vaughn *et al.*, 2011). The grow-bag media composition may possibly be either inorganic (e.g. perlite, rockwool, vermiculite, gravel, sand, pumice, zeolite, tuff, volcanic porous rock, and expanded clay granules, etc.) or organic in nature (Papadopoulos *et al.*, 2008; Gruda *et al.*, 2016b). Currently, organic materials would meet the requirement of being environment-friendly in the commercial sector (Gruda, 2012; Barrett *et al.*, 2016) and have become the focus of most intensive research attributed to their widespread availability, low cost, easy disposal, renewable and eco-friendly nature (Raviv, 2013; Gruda *et al.*, 2018). As the importance of soilless culture is likely to rise in the near future, it is essential to take research work towards identifying new materials that are environmentally sustainable, commercially viable and able to perform as well as those they are replacing (Barret *et al.*, 2016).

Nowadays, the most available and effective organic substrates are coir pith, vermicompost, peat, etc. Coir is a 100% organic naturally occurring fiber derived from a renewable resource of coconut husk. Raw coir pith consists of 35 per cent cellulose, 25.2 per cent lignin, 7.5 per cent pentosanes, 1.8 per cent fat and resins, 8.7 per cent ash, 11.9 per cent moisture and 10.6 per cent of other nutrients (Tripetchkul *et al.*, 2012). Because of its high C: N ratio (117: 1) (Noguera *et al.*, 2000) and high lignin under natural conditions, its degradation and mineralization rates are very slow, preventing its direct use as organic manure. A study on coir pith, sewage sludge and compost incorporated equally in garden soil, silt and leaf mould showed that the incorporation of coir pith and compost lowered the pH, maintained optimum EC and increased the organic carbon content improving nutrient uptake, yield and quality of marigold (Ahmad *et al.*, 2012). Vermicompost is peat like material containing plant growth hormones, enzymes and plant available nutrients promoting crop growth and yield (Atiyeh *et al.*, 2000). Dhaincha is an ideal quick growing and largely grown green manure crop. Its dry matter as a powder can also be used in the mixture of growing media as it is easily decomposable and supplier of organic carbon and nitrogen.

Fourier transform infrared (FT-IR) spectroscopy analysis is one of the most promising tool for characterizing heterogeneous organic matter by providing comprehensive information on the composition, properties and behaviour of the samples (Cuetos *et al.*, 2010). In the present instrumental investigation, compost maturity and lignocellulosic organic substances predominant in coir pith, vermicompost and dhaincha powder were characterized based on the presence of functional groups by FT-IR spectroscopy.

MATERIALS AND METHODS

Collection of substrate samples

Raw coir pith blocks were obtained from an Agri-Clinic centre, Trichy, Tamil Nadu and soaked in water to loosen the pith fibers and sun-dried. Vermicompost was collected from vermicompost production centre, Department of Agronomy, Anbil Dharmalingam Agricultural College and Research Institute (ADAC&RI), Trichy. The obtained vermicompost was thoroughly mixed and air-dried. After drying, the samples were stored for analysis. Dhaincha (*Sesbania aculeata*) plants were harvested from the ADAC&RI field, chopped into pieces, dried, ground as a powder in a flour mill and stored (Fig. 1).

Sample preparation for FT-IR analysis

For the substrates viz., coir pith, vermicompost and dhaincha FT-IR spectra were obtained on FT-IR spectrometer (Thermo Scientific Nicolet iS10 model with DTGS KBr detector). In solid film (pellet) technique of sample preparation, 1mg of dried sample along with 100 mg) KBr (spectroscopy grade) was homogenized and compressed to pellet (1mm thickness, 13 mm diameter) using a hydraulic press (Fig. 2). Spectra were recorded over the frequency range of 4000-400 cm^{-1} with 4 cm^{-1} resolution averaging 32 scans and corrected against air as background. The spectra collected were finally processed using OMNIC Spectra software (Ravindran *et al.*, 2013).

RESULTS AND DISCUSSION

FT-IR spectroscopy analysis

Solid-state spectroscopy is the most powerful tool which is used for examining the carbon composition of organic materials. One among them is FT-IR spectroscopy providing structural and compositional information on the functional groups present in the samples of organic substrates. Thus, this technique aids to confirm the products of decomposition containing several functional groups viz., polypeptides, polysaccharides, lignin, aliphatic, aromatic, carboxylic, phenolic groups existing in the substrates. In the present study, the spectra's different absorption peaks/ pattern and values showed the presence or absence of specific functional groups in the samples. In numerous FT-IR studies, relevant peaks attributing to specific functional groups/ and compounds were ascertained and these peaks were used as a guide for interpretation (Table 1).

FT-IR spectra of coir pith

Coir pith is an indigenously available agricultural organic solid byproduct, generated during the process of extraction of fibers from coconut husk. Before the last 20 years, coir pith was considered as a waste product of the extraction process and was dumped outside of coir

Table 1. Assignment of typical infrared bands for grow media substrates from FT-IR spectra.

S. No.	Band position* (cm ⁻¹)	Vibration*	Functional group or component*	Wavelengths obtained for grow media substrates from FTIR		
				Coir pith	Vermi compost	Dhaincha
1.	3200-3500 (Broadband)	O-H stretch	Alcohols and phenols	3334.66	3291.75	3294.28
2.	2925-2850 (Peak)	C-H stretch	Aliphatic nature – Degradation of cellulose, hemicelluloses, lipids, fats	2922.49	2918.01	2917.63
3.	1738–1709 (Peak)	C=O stretch	Unconjugated ketone, carbonyl and ester groups	-	-	1733.32
4.	1600-1650	C=O stretch	Carbonyl group of hemicellulose/lignin/ amide groups	1608.61	1634.71	1613.33
5.	1649-1521	C=C aromatic structure	Mineralization of protein, cellulose, hemicelluloses. Compost maturity	-	1549.85	-
5.	1515-1510	Aromatic C=C stretch	Lignin	1515.44	1514.87	1512.88
6.	1425-1410	COO ⁻ stretch	Carboxylic acids	1423.10	1421.63	1422.27
7.	1095-1030 (Sharp peak)	C-O-C stretch	Polysaccharides	1031.68	1053.95	1031.74
8.	785-800	C-O stretch	Carbonate/and Silica	-	789.69	-

*Interpretive Source :Rout and Arulmozhiselvan (2019); Bhat *et al.* (2017); Jahan and Mun (2009)

fibre mills, causing large environmental pollution issues and serious health hazards of its own. When every 10 tons of coconut husks utilized for coir extraction, 1.6 ton of coir pith was obtained as a byproduct (Coir Board, International Coir Fair, 2016). During 2012, there was an accumulated stock of 10 million tons of coir pith in southern states (Reghuvaran and Ravindranath, 2014), while in all over India, only 10 lakh tons of coir pith are

produced annually (Coir Board, India International Coir Fair, 2016). With the development of commercial horticulture and reduction in sphagnum peat availability, coco peat has become an internationally recognized ideal soil amendment and component of soilless container media for horticultural plants. In addition, coir pith also acts as an absorbent for eliminating pollutants from wastewater (Ali *et al.*, 2012).



a) Sun drying of coir pith



b) Air drying of vermicompost



c) Dhaincha harvesting and powdering

Fig. 1. Processing of growing media substrates.

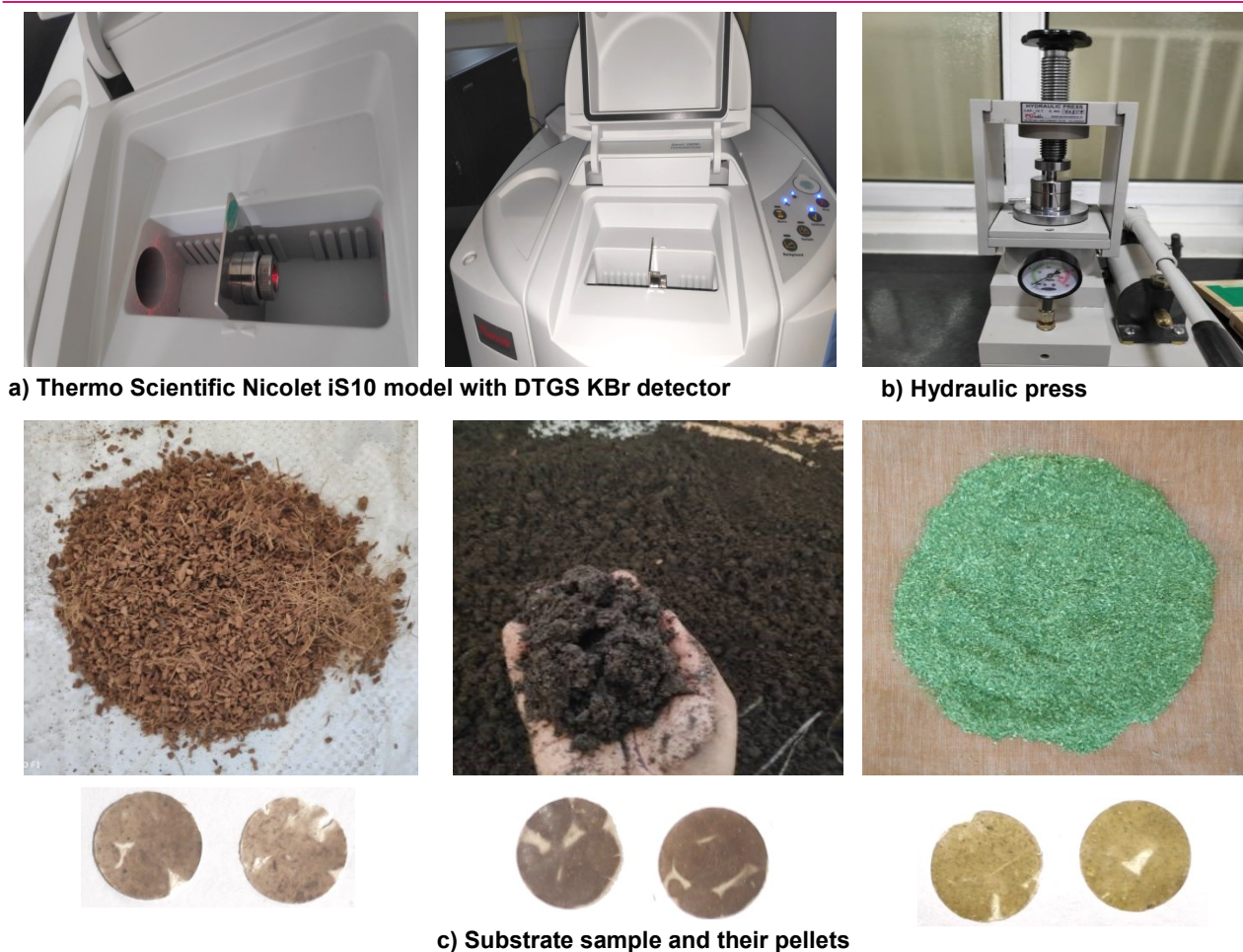


Fig. 2. Media pellet preparation by solid film technique in FT-IR.

The analysis of the FT-IR spectra of coir pith (Fig. 3) showed the presence of lignin, cellulose and hemicellulose, which are confirming the main characteristic of natural fibers. In general, the IR spectra with a broad, round band in between $3200-3600\text{ cm}^{-1}$ indicates axial deformation of the hydroxyl (O-H) group representing the presence of alcohols (Saberikhahe *et al.*, 2013). The exhibition of broadband at 3334.66 cm^{-1} might be indicative of the presence of stretch vibration of bonded hydroxyl groups from cellulose structure (Anirudhan *et al.*, 2007) on the coir dust. The weak band at 2922.49 cm^{-1} would have been caused by C-H stretch, which reflects the aliphatic nature of coir pith (Lazimet *et al.*, 2015). The peak at 1608.61 cm^{-1} might be the reflection of the presence of carbonyl group (C=O) of hemicellulose in coir pith. Similar findings have been reported by Ammar *et al.* (2014); Rout and Arulmozhiselvan (2019).

The absorption peak at 1515.44 cm^{-1} might be the axial stretch of aromatic C=C groups that ensures the presence of lignin, a prominent constituent of coir pith, as reported by Boeriu *et al.* (2004) and Lazimet *et al.* (2015). The presence of lignin is a sign of a complex carbon backbone and a high degree of polymerisation, impeding resistance against degradation. The vibration at

1423.01 cm^{-1} might be corresponding to the $-\text{COO}-$ antisymmetric stretching of carboxylic acids as per the reports of Bhat *et al.* (2017). The characteristic peak at 1370.27 cm^{-1} could be due to weak vibration of OH deformation of phenolic group, CH_3 bending, or C-O stretching. Similar findings are reported by Lailiet *et al.* (2010) in humic acids present in coir pith.

All the substrates showed a sharp peak between 1095 and 1030 cm^{-1} attributable to $-\text{OCO}-$ and $-\text{C}-\text{O}-$ stretch in alcohols, esters and ethers, which would also show the presence of lactones and polysaccharides as stated by Davila-Rodriguez *et al.* (2009).

FT-IR spectra of vermicompost

Vermicompost comes as an excellent product since it is homogenous has desirable aesthetics, has minimal contamination levels, and tends to hold more nutrients over a longer period without adversely impacting the environment (Ndegwa and Thompson, 2000). Mineralization of organic matter and degradation of complex aromatics (lignin, polyphenols) into simpler compounds (carbohydrates, lipids) can be analyzed by FT-IR spectroscopy. This technique indicates the stages of compost maturity and stability of compounds of degradation present. Therefore, it appears as a promising technique

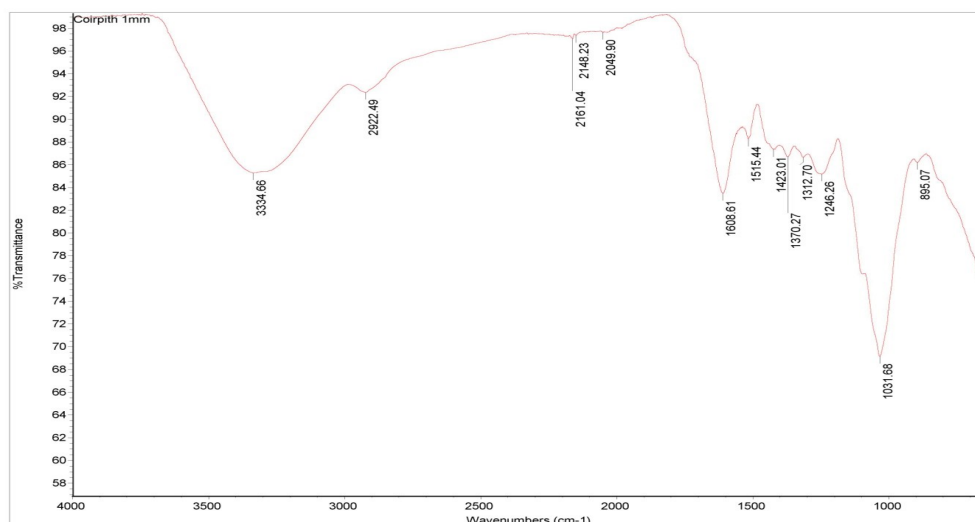


Fig. 3. FT-IR spectra of coir pith.

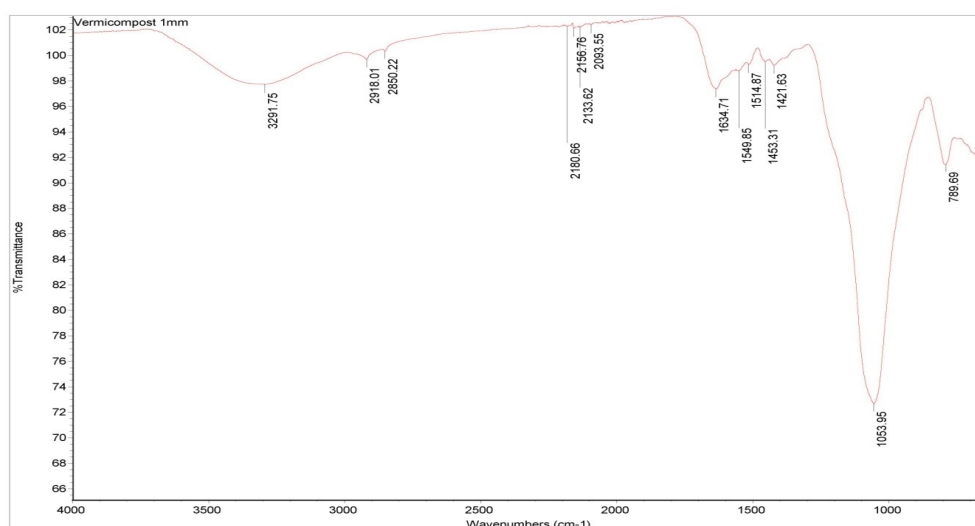


Fig. 4. FT-IR spectra of vermicompost.

to identify functional groups in compost in the process of vermicomposting. The spectral bands symbolize the presence or absence of certain functional groups aiding to predict the degradation or stabilization process at different stages.

In the recorded infrared spectra (Fig. 4), an intense wide band in between $3200 - 3500 \text{ cm}^{-1}$ might indicate -OH stretching of alcohols and phenols group. Similar findings were reported by Pandey and Pitman (2003) in fungi; Simkovic *et al.* (2008) in soil organic matter; Amir *et al.* (2010) in humic acids and Hussain *et al.* (2016) in vermicompost. The decrease in intensity of band from 3291.75 to 2918.01 cm^{-1} would be the indication of the evidence of intense biodegradation ensuring compost maturity. Similar results were given by Ganguly and Chakraborty (2019).

The band at wave number 1634.71 cm^{-1} shows the existence of lignin. The peak value around 1549.85 cm^{-1} indicate $\text{C}=\text{C}$ aromatic structure formed during mineralization of protein, cellulose and hemicelluloses. This

increase in the aromatic carbon is considered as an indicator of an increasing degree of organic matter humification associated with compost maturity and stability and their transformation to the highly humified substrate. These interpretations corroborate the reports of Huag *et al.* (2006) who have indicated an increase in polycondensed structures by detecting with FT-IR Spectra, and concluded that the mature compost derived from pig manure with saw dust contained more stable organic matter.

In another study, FT-IR spectra exhibited an increase in absorbance at 1453.31 , 1421.63 cm^{-1} and a strong increase at 1053.95 cm^{-1} , also the appearance of new small peaks around 1634.71 and 1514.87 cm^{-1} which were mainly attributed to aromatic ethers from lignin-like structures. This confirms the decrease in aliphatic structures and the increase in more oxidized, polycondensed aromatic structures as reported by Ammar *et al.* (2014) in lignin samples, while vibration at 789.69 cm^{-1} might be the indication of C-O stretch associated

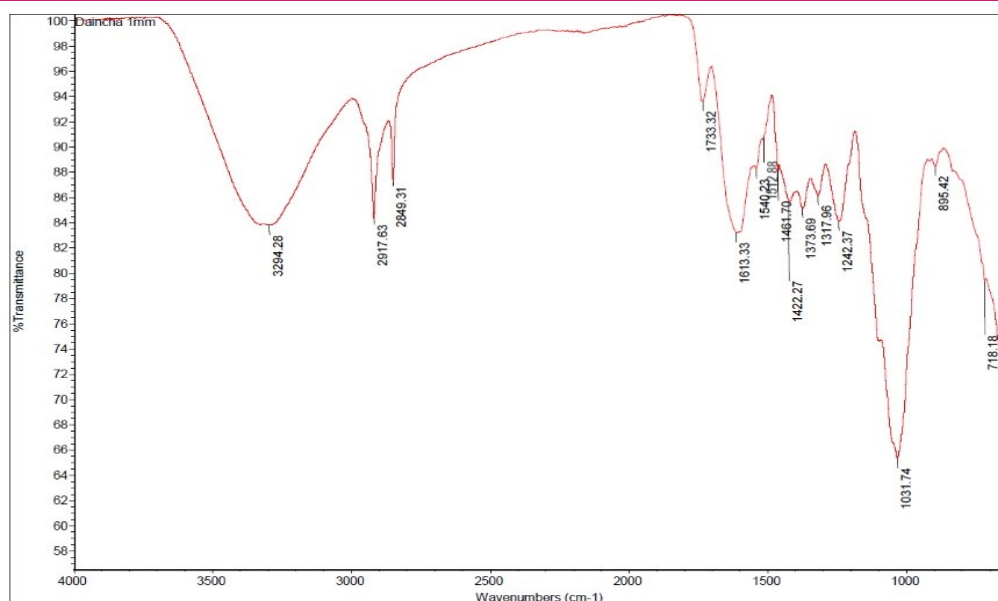


Fig. 5. FT-IR spectra of Dhaincha.

with carbonate and silica as observed from the FTIR results of vermicomposts by Carrasquero-Duran and Flores (2009) and Ravindran *et al.* (2008).

FT-IR spectra of dhaincha

Green manure is an excellent natural source of nitrogen for cultivated crops. Dhaincha, a stem nodulating green manure crop, is widely available in many tropical countries of Asia and Africa and is considered the most promising of the green manure crops for wetland rice since it has high nitrogen fixing ability in standing water. The major use of the crop has been for fodder for livestock and green manure to improve soil fertility. FT-IR spectra were recorded for the dry matter of dhaincha, which was ground as a powder (Fig. 5) and based on the assignments made by Faix (1991) the spectral pattern can be interpreted as follows:

In the region between 3412–3460 cm^{-1} , the absorbance at 3294.28 cm^{-1} correspond to $-\text{OH}$ stretching vibrations of polysaccharides and amino groups. The peak value around 3000–2842 cm^{-1} have been assigned to C-H stretch in methyl and methylene group of lignin extracted from different non-woods. In the present sample, such peaks were found at 2917.63 and 2849.31 cm^{-1} .

The presence of vibration at 1738–1709 cm^{-1} would be due to C=O stretch associated with an unconjugated ketone, carbonyl and ester groups. Such peak appeared at 1733.32 cm^{-1} for the present sample. The bands around 1610 and 1422 cm^{-1} depict the aromatic skeleton vibrations plus C=O stretching and aromatic skeleton vibrations plus CH in plane deformation. The spectra showing signs of absorbance between 1505 and 1515 and 1460–1470 cm^{-1} can be associated with aromatic skeleton vibration and C-H deformations

(asymmetric in $-\text{CH}_3$ and $-\text{CH}_2$ of lignin) respectively.

As per the reports of Jahan and Mun (2009), the sharp peak appearing at 1031.74 would be the indication of the aromatic C-H in plane deformation plus C-O deformation in primary alcohols plus C-H stretching (unconjugated) of polysaccharides.

Advantages and limitations

FT-IR spectroscopy is used to study the substrates without any chemical treatment, which would cause unsuitable reactions. It is simple, quick, highly sensitive, informative for evaluation of the functional groups in organic substrates and environment friendly as it produces remarkably less waste. Solid, liquid, as well as gas can be analyzed with FT-IR spectroscopy. The disappearance or the appearance of a new band in the FT-IR spectra provides essential information about the organic matter evolution and its interaction with heavy metals. Organic and inorganic compounds can also be easily identified with the spectra obtained.

FT-IR spectroscopy is a single beam technique. It cannot detect atoms or monoatomic ions. It is impossible to measure the level of an element in a substance unless it is present as a part of a molecule whose spectrum can be detected (Bhat *et al.*, 2017).

Conclusion

In the present study, FT-IR analysis in coir pith and dhaincha samples confirmed the occurrence of lignin, hemicellulose and cellulose, which are the main characteristics of natural fibers with high water-holding and cation exchange capacity. The presence of alcoholic and carboxylic groups would be indicative of stages of compost maturity and stability. It also showed the pres-

ence of functional groups on their surfaces, which provide a conducive physical, chemical, and biological environment for crop growth. Therefore, these renewable and environmentally sustainable lignocellulosic organic materials, viz., coir pith, vermicompost and dhaincha could be recognized as ideal soilless substrates for preparing growth media for containerized crop production. Further, utilizing these organic materials paves the way for recycling organic wastes in an environmentally friendly manner. Therefore, an ideal soilless media while improving crop productivity can minimize the risks associated with soil-based cultivation.

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Conflict of interest

The authors declare that they have no conflict of interest.

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