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Properties of different graded coir pith by Keen-Raczkowski box and Brunauer-Emmett-Teller analysis

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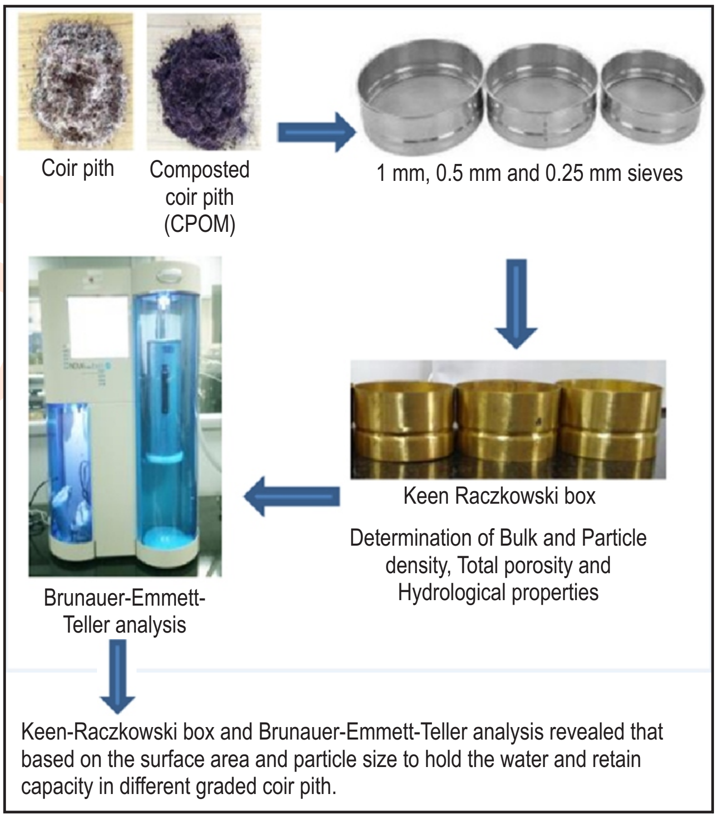
Abstract

Aim: To evaluate the physical and hydrological properties of different graded coir pith and composted coir pith (CPOM) following the Keen-Raczkowski box and Brunauer-Emmett-Teller (BET) analysis.

Methodology: The coir pith was collected and composted by PITH PLUS (*Pleurotus-sajor-caju*). Thereafter, the coir pith and composted coir pith were segregated into different groups based on the size of the particles as 1.0 mm (1000 microns), 0.5 mm (500 microns), and 0.25 mm (250 microns). Based on particle size, the hydrological properties of coir pith and composted coir pith were determined. The physical and hydrological properties were estimated by the Keen-Raczkowski box method and Brunauer-Emmett-Teller analysis.

Results: Different graded coir pith and composted coir pith of size 0.25 mm showed the highest bulk density (0.60 and 0.48 g cm^{-3}), followed by 0.5 mm size coir pith and composted coir pith, respectively. The highest particle density (0.18 and 0.19 g cm^{-3}) was registered in 1.0 mm coir pith and composted coir pith whereas the lowest particle density was observed in 0.25 mm size coir pith (0.15 g cm^{-3}). The water-holding capacity (817.93 % and 806.97 %) and water in air-dry substrate (25.03 % and 36.094 %) was high in 0.25 mm coir pith and composted coir pith.

Interpretation: A 0.25 mm grade of coir pith and composted coir pith showed highest water holding and retaining capacity due to a greater number of small particles being compactly arranged and holding more surface area, and innumerable micropores than other graded particles.



Key words: BET analysis, Coir pith, Composted coir pith, Water holding capacity

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Introduction

Coir is made of husk and short fibers from the nut mesocarp of *Cocos nucifera*, which are the waste product of coconut industry. The process of separating the fibre from the coconut husk produces coir pith, which is typically disposed off as agricultural waste. Each tonne of intact coconut fibre generated two tonnes of pith. Approximately, 7.5×10^5 tonnes of coir pith are generated annually in India, and currently it is estimated that 10×10^6 metric tonnes of accumulated stock is present in the southern states of India (Narendar and Priya Dasan, 2024). An estimated 0.5 million tons of coir material are lost annually in India, compared to 3.6 million tons worldwide. (Barbara *et al.,* 2020). Usually, they are burned or disposed as hillocks (Stephy and Beevi, 2023).

Owing to lesser environmental degradation, the hillocks of coir pith are either gathered or disposed off pose a major risk not only to the environment but also to humans. It doesn't begin to deteriorate until it is ten years old due to the presence of high concentration of lignin (Nattudurai *et al.,* 2014). Pith has a pentosan/lignin ratio of 1:0.30, and a minimum of 1:0.50 is needed for the soil to decompose moderately (Namasivayam *et al.,* 2001). Burning of agricultural waste produces more greenhouse gases (Prakash *et al.,* 2021). Coir provides a favourable balance between air and water, similar to peat (Barrett *et al.,* 2016), and a higher re-wetting capacity than peat (Blok and Wever, 2008). Coconut coir is a readily renewable, pH-neutral, non-hydrophobic amendment that aerates, improves water retention, and is eco-friendlier substrate than peat moss. It is well known that coconut is a source of revenue for Indian marginal growers. Coconuts are processed in endeavors to extract oil from desiccated parts (copra). The husk or mesocarp produced prior to the full cycle of maturity is enormous and was once considered as trash (Mathew *et al.,* 2000). These husks are being utilized as raw ingredients to make coir fiber. The light weight, flexible material is provided while the husk is cracked open to release the coir fiber. This soft substance is coir and forms approximately 50-60% of the total husk weight.

In addition, to act as an effective soil-less growing media, coir needs to be further processed, which can lead to a low standardization of biological, chemical, or physical properties of the material. In this study, we focused on the physical and hydrological characteristics of different graded coir pith and explored them by Keen-Raczkowski box and Brunauer-Emmett-Teller (BET) analysis. Previous researches have mostly revealed the physical properties of coir pith. This study shows how different graded coir pith functions in terms of water holding and retaining ability as well as the interesting properties of pore radius, surface area, and total pore volume.

Materials and Methods

Collection of test material and processing: At the Department of Agronomy, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu, India, experiments were conducted from 2020 to 2021 on the Physical and hydrological qualities of various graded coir pith and composted coir pith. The coir pith was then inoculated with a proprietary bio-formulation, such as PITH PLUS (*Pleurotus sajor caju*), and enhanced with urea to begin the composting process. After 30 days, there was a noticeable decrease in the amount of lignin and cellulose and an increase in total nitrogen and other nutritional components. Coir Pith Organic Manure (CPOM), sometimes referred to as composted coir pith (Boraiah *et al.*, 2015).

Grading of coir pith and composted coir pith: The coir pith and composted coir pith samples were transported to the laboratory, after sun drying for 3-4 days to eliminate moisture. The sample was carefully cleared of extraneous elements, including dust, pebbles, and tiny stones. To divide the coir pith and Coir Pith Organic Manure into several groups according to the size of the particles for additional examination, they were subsequently sieved several times with varying mesh size of 1.0 mm (1000 microns), 0.5 mm (500 microns), and 0.25 mm (250 microns).

Keen-Rackzowski Box: The Keen box was cleaned, dried weighed and its dimensions were measured. Whatman No. 1 and 44 filter papers were placed at the bottom of the sharp box. Subsequently, the box was completely and evenly packed with air-dried, sieved (2 mm) soilless substrates. Keen Box containing substrates was reweighed. The box was then placed in the soaking tray and progressively filled with water to a height of 1.0 cm above the base. For balance, the dish was covered and left for at least 12 hrs. This was confirmed by a persistent, brilliant layer of water at the soil-less media surface.

Eventually, the box was weighed, cleaned, and gently taken out of the water. After cutting off the enlarged soilless substrate, a pre-weighed watch glass was created, and the glass was once more weighed using an expanded soilless medium. After being oven-dried at 105^0C, the soilless substrates for the sharp box and watch glass were weighed consistently. To determine the weight of the water absorbed by the filter paper alone, a blank test using only a keen box and filter paper was also conducted concurrently. The physical characteristics of the soilless substrate were ascertained using this technique.

The various grades of sieved coir pith and composted coir pith physical and hydrological properties of bulk density, particle density, total porosity, water holding capacity, water in an air-dry substrate, and volume expansion were estimated by Keen - Raczkowski box method (Piper, 1966). The moisture retention of samples was determined by daily weighing method (Keenbox). Daily weighed different-graded coir pith samples, followed by the previous day's water balance.

Brunauer-Emmett-Teller (BET): Nitrogen adsorption at 77 K was used to determine the specific surface area, pore volume, and average pore size of coir pith and composted coir pith, following the Brunauer-Emmett-Teller method. The analyses were performed using a NOVA 1200 instrument (Quantachrome, USA), at the Department of Nano Science and Technology, Tamil Nadu Agricultural University, Coimbatore (India). This method is based on the determination of the volumes of gas adsorbed and desorbed at different relative pressures. Before analysis, all the samples were powdered and subjected to degasification at 150 °C for 2 hr. Brunauer - Emmett - Teller (BET) analysis of average pore radius, surface area, and total pore volume of different graded coir pith and composted coir pith produced at different temperatures were determined by BET equation, t-plot method, and single point adsorption, total pore volume analysis, respectively.

Statistical analysis: Each characterization data set's results were derived using the mean technique of three replicates, and a Complete Randomization Design was used for statistical analysis. The statistical analysis of the data on parameters examined during study was conducted following Gomez and Gomez (1984) analysis. The crucial difference was calculated at a five percent probability level in cases where the treatment differences were found significant ("F" test). "NS" stands for "Non-Significant" for treatment differences.

Results and Discussion

Coir pith is essentially utilized as soilless media for greenhouse and home gardening. In this case, the size of the coir's particles matters. The coir pith medium provides sufficient water, oxygen, and nutrients to meet the requirement of roots. It ought to provide the plants with tangible support as well. The goal of sieve fractionation (Agnew *et al.,* 2003) is to determine the physical properties of individual particles that directly affect a growth medium's ability to operate.

The most important parameters that indicate the coir pith's ability to function for structural support, water, solute movement, and aeration. The pore space of the coir pith is the portion occupied by air and water, which depends upon the texture, compaction, and aggregation of coir pith substrates. Analysis of variance shows that bulk density, particle density, and total porosity of different graded coir pith and composted coir pith differed significantly (Table 1). Among the different graded coir pith and composted coir pith, the highest bulk density was registered by 0.25 mm (0.60 and 0.48 g cm^{-3}), followed by 0.5 mm of coir pith and Coir Pith Organic Manure (CPOM), respectively. The highest particle density (0.18 and 0.19 g cm^{-3}) was registered in 1.0 mm coir pith and composted coir pith whereas the lowest particle density was observed with 0.25 mm of coir pith (0.15 g cm^{-3}) and CPOM (0.16 g cm^{-3}). The total porosity was higher with 1.0 mm coir pith (33.92 %) and CPOM (44.81 %). The lowest porosity was registered at 0.25 mm of coir pith (26.05 %) and CPOM (34.25 %). The bulk density observed for different graded coir pith and Coir Pith Organic Manure (CPOM) was rather high (0.42 to 0.60 g cm^{-3}). It is believed that plants experience mechanical impedance at high bulk densities. Any solid media that effectively anchors the roots of the plant must be heavy enough to keep a potted plant from toppling over from its weight (Nelson, 1985). However, there is a particular benefit to the current situation's relatively low bulk density, particularly when taking terrace gardening into account.

The results of the investigation carried out for the assessment of water relation characteristics of different graded coir pith and composted coir pith are presented in Table 1. The highest water holding capacity and water in the air-dry substrate were registered with 0.25 mm of coir pith (817.93 % and 25.03%) and composted coir pith (806.97% and 36.09%) whereas the lowest water holding capacity and water in the air-dry substrate was registered with 1.0 mm of coir pith and CPOM. The highest volume of expansion was observed with 1.0 mm of coir pith (18.56) and CPOM (12.91 %) and the lowest volume of expansion was found in vermiculite 0.25 mm of coir pith and CPOM. The amount of pore space between the individual coir material particles in the container is a function of their size, shape, and spatial arrangement, and is stated as a percentage of porosity (Handreck and Black, 1984). According to Anbarasu and Arumugam (2021), there are three basic categories of porosity: absolute porosity, air circulation porosity, and water-holding porosity. According to Bethke (1986), absolute porosity is the percentage of a developing medium's total pore space that isn't filled with solid particles.

Table 1: Different graded coir pith and composted coir pith (CPOM) by Keen-Raczkowski box

Treatments	**Bulk density (gm cm^{-3})**	**Particle density (gm cm^{-3})**	**Total porosity (%)**	**Maximum water holding capacity (%)**	**Water in an air-dry substrate (%)**	**Volume of expansion (%)**
CP 1.0 mm	0.547	0.185	33.924	756.306	15.602	18.564
CP 0.5 mm	0.555	0.168	30.227	798.108	19.552	11.751
CP 0.25 mm	0.603	0.157	26.052	817.938	25.037	9.444
CPOM 1.0 mm	0.427	0.191	44.812	749.541	25.843	12.919
CPOM 0.5 mm	0.445	0.185	41.577	781.447	22.036	7.206
CPOM 0.25 mm	0.484	0.166	34.257	806.975	36.094	1.194
SEd	0.102	0.035	5.011	16.618	4.793	2.031
CD (0.05)	0.291	0.100	18.031	47.480	11.696	5.802

Table 2: Determination of water retaining capacity of different graded coir pith and composted coir pith (CPOM)

Day	CP 1.0 mm	CP 0.5 mm	CP 0.25 mm	CPOM 1.0 mm	CPOM 0.5 mm	CPOM 0.25 mm
*KRB weight	48.24	48.75	48.85	47.78	51.27	49.53
KRB + sample	63.01	63.76	71.36	55.07	60.32	62.51
Sample weight	14.77	15.01	22.51	7.29	9.05	12.98
Initial day	127.27	131.52	151.07	110.05	116.51	123.91
Day 1	121.52	126.76	147.97	106.35	112.7	119.36
Day 2	114.76	119.64	143.12	101.84	107.64	113.52
Day 3	108.37	111.84	136.97	97.10	102.92	108.91
Day 4	103.27	106.17	131.57	92.49	98.43	104.16
Day 5	94.99	97.35	123.42	86.28	92.32	98.96
Day 6	91.3	92.47	117.87	81.52	87.85	94.86
Day 7	87.14	88.18	113.38	77.48	84.22	91.71
Day 8	84.2	85.11	108.85	74.28	81.03	88.81
Day 9	81.2	82.32	104.81	71.09	78.13	86.09
Day 10	78.07	78.95	100.07	67.63	74.60	82.79
Day 11	74.00	74.87	94.41	64.26	70.97	78.74
Day 12	69.86	70.70	88.37	61.10	67.51	70.51
Day 13	67.01	67.63	83.26	58.67	64.99	61.89
Day 14	64.60	65.07	79.32	56.64	62.81	59.08
Day 15	61.50	62.64	75.86	55.16	60.90	56.03
Day 16	61.28	62.00	73.27	54.92	60.26	54.07
Day 17	61.00	61.34	70.79	54.81	60.06	52.57
Day 18	60.96	61.34	70.09	54.81	60.05	52.4
Day 19	60.68	61.30	69.90	54.79	60.02	52.32
Day 20	60.68	61.30	69.90	54.79	60.02	52.32
SEd	1.72	1.76	2.15	1.53	1.66	1.69
CD (0.05)	3.41	3.48	4.26	3.03	3.29	3.36

Statistical analyses were done from day 1 to day 20

Table 3: Different graded coir pith and composted coir pith (CPOM) by Brunauer-Emmett-Teller analysis

Treatments	Average pore radius (nm)	Surface area ($m^2 g^{-1}$)	Total pore volume ($cc\ g^{-1}$)
CP 1.0 mm	1.2448e+00	4.072	2.5346e-03
CP 0.5 mm	4.4826e-01	2.590	3.5634e-04
CP 0.25 mm	7.8501e-02	1.584	6.1169e-04
CPOM 1.0 mm	1.4134e-01	3.941	1.9020e-04
CPOM 0.5 mm	3.7345e-01	2.773	2.9597e-04
CPOM 0.25 mm	6.6513e-02	2.326	6.1336e-04

Porosity is resolved basically by the scope of particle size present in the coir pith and composted coir pith medium (Havis and Hamilton, 1976). The larger particles and their porosity do not pack as tightly as the smaller particles do. The air circulation between the porosities enhances the water holding capacity, and after imbibing water, it enlarged the pore sizes of the coir pith (Priyadarshini *et al.,* 2021). At the point when the size of the coir essence molecule expanded, the water-holding porosity diminished which eventually expanded the air circulation porosity. This expansion of 0.25 mm of coir pith and composted coir pith had the highest water holding capacity and water in the air-dry substrate. In the assessments, the moisture maintenance was significantly reduced to zero as a retention capacity. Larger particles had the lowest capacity for moisture retention, while smaller particles-maintained moisture for a longer period of time. Full-scale pores efficiently ejected the water atoms into the atmosphere and functioned as an eliminator in the larger particles, as tiny holes may have served as a crucial component in retaining moisture in the smaller particles. The water maintenance limit depends on the specific surface area of the medium as well as the quantity, size and distribution of pores. According to Jeyaseeli and Paul Raj (2010), the nature, size, and dispersion of the pores that determined the dampness retentivity caused the water absorptivity to be low in larger particles and high in more modest ones. As a result, it should be clear that the pores play a critical role in retaining moisture in the coir essence grades.

The moisture retention was determined in coir pith and composted coir pith (CPOM) on consecutive days as a function of time. The percentage of moisture retention decreased in all particles as the days advanced. The highest percentage of moisture retention was observed in the 0.25 mm particle size and the lowest in 1.00 mm particle size. The highest percentage of moisture retention after twenty days was recorded in 0.25 mm particles from 147.97 to 69.90 of coir pith and 119.36 to 52.32 of composted coir pith respectively from day 1 to day 20. The percentage retention observed during the first day in 1.00 mm size particle decreased significantly after 21 days of observation, i.e., from 121.52 to 60.68 and 106.35 to 54.79 of coir pith and composted coir pith, respectively (Table 2). The specific surface area of the medium as well as the number and size distribution of pores determines the amount of water retained in the medium. The texture of the medium accounted 80% of the variances in the percentage increase in water retention (Sharma and Bhushan, 2001). However, an excessively large pore size reduces the media's capacity to hold water.

The results of the Brunauer-Emmett-Teller method specific surface area analyses are provided in Table 3. The surface area and pore volumes produced at various sizes of coir pith and composted coir pith differed with weight and nitrogen adsorption. The lowest surface area had the highest pore space, the highest pore space had the lowest surface area and vice versa. The highest average pore radius (7.8501e-02 and 6.6513e-02 nm), total pore volume (6.1169e-04 and 6.1336e-04 cc g^{-1}), and lowest surface area (1.584 and 2.326) was registered at 0.25 mm of coir pith and composted coir pith (CPOM), respectively. The lowest average pore radius (1.2448e+00 and 1.4134e-01 nm), total pore volume (2.5346e-03 and 1.9020e-04 cc g^{-1}), and highest surface area (4.072 and 3.941m^2 g^{-1}) was recorded at 1.00 mm of coir pith and composted coir pith. The highest Brunauer-Emmett-Teller specific surface areas were observed for all graded coir pith and composted coir pith (CPOM). Among the distinctive reviewed coir substance 0.25 mm enlisted more pore range and pore volume of both coir essence and treated the soil coir essence because of less surface territory.

Due to the presence of infinite tiny pores, a more subdued and planned molecule held on to more water than the coarser particles that had larger but more constrained amount of full-scale pores. As the usual size of the coir pith and composted coir pith increased, the total surface area of the relative number of particles present in a unit volume decreased. The water absorption capacity of coir pith increased along with the surface area of different grades. As the particle diameter shrunk, the total amount of water in the medium rose because water was not only absorbed but also retained on the surface of these particles as a film (Anil *et al.,* 2021). Moreover, the composted coir pith was registered as the lowest level compared to the coir pith mainly due to the disintegration of their structure by *Pleurotus sajor caju* species.

This study provides valuable insights into the coir pith and the decomposed coir pith. The bulk density decreased as particle size was nurtured and was found to be high in small particles (0.25 mm). There was a direct correlation between the particle size and water-holding capacity of different grades of coir pith. Because they had more micropores per unit area, the smaller, more compactly organized particles absorbed more water than the coarser particles. The water holding and maintenance limits were dependent on the quantity and size of pores in the medium as well as specific surface area.

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