

# Preparation of Coconut shell and Pista shell Charcoal and finishing Natural Cotton and Bamboo Fabric materials – An Eco-Friendly Approach

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## ABSTRACT

Charcoal are of natural origin has anti-odour properties by controlling the metabolism of odour causing bacteria and fungi. In the present study, charcoal prepared from natural sources are finished on to natural cotton and bamboo fabrics with the aim of developing anti-odour fabrics. Finished fabrics were subjected to anti-odour testing using modified artificial sweat studies against the test bacterial specimens (*Staphylococcus aureus* and *Micrococcus luteus*). The infection associated with odour causing organisms were considered significant and hence the antibacterial and antifungal activity was tested using standard EN ISO 20645 test method and AATCC-30 test method respectively. The wicking study was conducted to investigate the absorbency efficiency of charcoal finished fabrics using AATCC TM 197 test method; and comfort property of air-permeability test was also conducted using ASTM D-737-96 method. No odour was recorded for all the test specimens finished with both coconut and pista charcoal finished fabrics. Antibacterial and antifungal activity test also revealed the efficacy of charcoal finished fabrics in terms of inhibitory zones against the test organisms. During the wicking test it was confirmed that the charcoal finished for odour control property does not have any impact on the absorbency of the fabrics indicating that nativity of the fabric was not changed. No significant difference in the air-permeability was observed for the charcoal finished fabric sample when compared to unfinished control fabric thus indicating that the finishing materials does not have any impact on the porosity of the fabrics. This study would be considered highly significant by providing an eco-friendly and sustainable products for different fields of applications by developing charcoal from waste recycle process.

**Keywords:** Coconut shell charcoal, Pista shell charcoal, Eco-friendly, Anti-odour, Wickability

## INTRODUCTION

Textile industry, currently focuses on high quality, innovative, functional textiles. Nowadays, consumers are in great aware of hygiene and they are in requirement of high standard textile products with wide variety range.

One of the important factors of the textile microbiome are skin microbiome as the skin is in direct contact with the clothes. The skin is slightly acidic in nature. Discrete skin sites are determined by various parameters such as, skin thickness, folds, density of hair follicles and glands which are the micro-environments with specific temperature, pH, sebum levels [(Gallo, 2017) (Grice and Segre, 2011) (Grice et al., 2009)]. The micro-organisms group differ greatly in composition, diversity and abundance depending on these microenvironments. Moist environments like toe webs, armpits, perineum have high temperature and humidity. These regions have high bacterial concentrations up to  $10^6$  organisms/  $\text{cm}^2$ . These include most of the species related to *Staphylococcus* or *Corynebacterium* [(Grice et al., 2009) (Costello et al., 2009) (Cundell, 2018)]. Clothes are also related to the odour intensity as skin debris, secretions, sebum, micro-organisms and odorous volatiles are transferred from the body to the garments. The micro-organisms that attach to the fibers use dirt or

sebum compounds as a substrate and they generate volatiles as by-products that results in mal-odour formation [(Munk et al., 2001) (Mc Queen et al., 2014) (Chung and Seok, 2012)]. The major odour causing micro-organisms are *Staphylococcus* [(Munk et al., 2001) (Dumas et al., 2009)] in specific *Staphylococcus epidermis* and *Staphylococcus aureus*, *Micrococcus* [(Kubota et al., 2012) (Takeuchi et al., 2013)] specifically *Micrococcus luteus*, *Bacillus* (Ara et al., 2006) mainly *Bacillus subtilis*, *Propionibacterium* [(James at al., 2004) (Rathinamoorthy and Thilagavathi, 2016)], *Corynebacterium* [(Dumas et al., 2009) (Dayan, 2011)] *Corynebacterium bovis*, *Corynebacterium striatum* species.

In many fields, such as medical field, food industries, industrial wear, frequent travelers use caps or helmets on their daily basis. So, their prolonged usage may cause high mal-odour formation, which can even lead to bacterial, fungal or any kind of skin infections, hair related infections like dandruff, itching, hair fall, etc., due to sweat formation. Hence this can be prevented by coating the fabric present in the inner side of caps or helmets with activated charcoal. Instead of using cosmetics like shampoo, conditioner, serum, etc., the natural way of coating the fabric with activated charcoal would be the best solution.

As a result of high heating of charcoal forms derivatives. These derivatives are called as activated charcoal. Usually, air around us consists of varieties of toxins, gases, dust and chemical particles which gets easily absorbed by normal clothing. But the activated charcoal finished clothing material has the capacity to entrap the toxins and other particles in the pores which are present in its internal structure. Further it also prevents the absorption process to any other medium. The increased pore sized present in the activated charcoal has the capability to entrap toxins and chemicals and prevent further absorption, with which the negatively charged pores will attract all positively charged molecules (toxins and gases). These properties of activated charcoal could be implemented in textile fields or in textile materials. Activated charcoal possess advantages as cleansing agent, anti-odour property and act as air filters (Mohan, 2020).

Thierry Le Blan and Arnaud Vatinel, (2018) conducted a study on the odour reduction properties of textile materials. A part of their study was involved with activated carbon treated fabrics. It was stated that the activated carbon was used as a functional material for anti-Microbial and odour control finishing on textile fabric. It was applied to the fabric through coating technique and it was tested. Tripathi et al., (2018) found that activated carbon fabric has many advantages like well-defined porous structure, flexibility, ease of lamination to various substrate and stability. (TSM Eza et al., 2014) found the effectiveness of activated carbon produced from coconut shell and oil palm shells as anti-odour on textile fabrics. The activated charcoal was prepared from coconut and oil palm shells. As a result of their work they observed that fabrics containing activated carbon were able to reduce odor to a great extent.

In present study, the natural wastes such as coconut shells and pista shells are used for producing activated charcoal. The activated charcoal was then finished to the cotton and bamboo fabric. These fabrics were chosen due to its good absorbency property and hence vertical wicking study and air permeability studies were performed. As the charcoal has anti-odour properties by controlling the odour metabolism of microbes, the anti-odour property of the charcoal finished fabric was investigated by modifying the artificial sweat study parameter. The microbial filtration efficiency shall be determined using this parameter for the finished fabric materials. The antibacterial and antifungal activity of the finished fabric was determined in terms of qualitative test. Based on these functional properties of charcoal finished fabrics, different types of head caps shall be fabricated in future for different applications.

## MATERIALS AND METHODS

### Selection of fabric – Cotton and Bamboo

The constructional parameter of the commercially-available woven fabrics of 100% cotton and 100% bamboo was used in the present study.



### Selection of charcoal sources

Charcoal from two different sources were selected based on the eco-friendly properties. As the coconut shell and pista shell were considered as waste and disposed either as for land filling or for incineration, these waste were considered to be the source of materials for the preparation of charcoal in the present study.



### Preparation of different types of charcoal – Coconut shell and Pista shell

The coconut shell was broken into several pieces (5mm x 5mm) of 2 to 3 months older were selected for this work. They were dried in shadow for a period of 2 weeks. The fully dried pieces were carbonized in a flash-and-fire-point instrument. The dry shells were placed inside a metallic container with small openings in the lid to create a low-oxygen environment inside the container and also to allow smoke and gases to come out. Initially, the temperature was set at 120°C and the speed of carbonization was observed to be slow.



The temperature was then raised gradually from 120°C to 260°C. After about 15min, white smoke appeared to come out. This lasted for about 5 min and then a yellowish gas emanated from the container, signaling the conversion of pieces to coconut charcoal. The container was then removed from the instrument and the coconut charcoal was allowed to cool at room temperature. The bamboo charcoal pieces, were further used to prepare the charcoal particles. The charcoal pieces were grounded and milled to convert into fine powder particles. The charcoal powder was sieved in a sieve (100 micron size). Fine powdered charcoal particles were stored at room temperature for further fabric finishing process. Similar procedure was carried out to prepare the pista shell charcoal particles.



### Fabric Pretreatment and finishing fabrics with prepared charcoal

In order to remove the added impurities in the fabrics, all the fabrics were subjected to pre washing cum relaxation process using 2 gpl of non-ionic detergent, with a MLR of 1:20 at 70°C for a period of 20 min and dried at room temperature.



The charcoal particles were applied on the fabrics with the recipe of solution concentration: 1% (w/v), Flexible acrylic binder: 0.5%, Wetting agent: 1% and the M:L Ratio: 1:20 using pad-dry-cure method (Table-1). The wet pick-up of the fabric was 100% for both cotton and bamboo fabric materials respectively. The treated fabrics were then dried in a drying chamber for 10 min at 80°C and then cured for another 4 min at 120°C in a curing chamber. All finished fabrics were further tested to investigate the functional properties.



### Antibacterial activity (EN ISO 20645)

The test specimens (coconut and pista charcoal finished Fabrics) were cut into pieces (20mm in diameter) and antibacterial activity was tested using standard EN ISO 20645 test method. All the test cultures (*Staphylococcus aureus* and *Micrococcus luteus*) were inoculated in a sterile Nutrient broth (Composition g/L: Peptone: 5g; Yeast extract: 5g, Beef extract: 3g, Sodium chloride: 5g; Final pH -  $7.0 \pm 0.2$ ) and allowed to attain the growth for 24 to 48 hours. Using sterile 4mm inoculating loop, one loop full of culture (*Staphylococcus aureus* and *Micrococcus luteus*) was transferred by swabbing all around the surface of the Mueller-Hinton agar plate (Composition g/L: Acid hydrolysate of Casein: 17.5g; Starch: 1.5g, Sodium chloride: 5.0g, Agar 17.0 g; Final pH -  $7.0 \pm 0.2$ ) and also covering the central area of the petridish. For each test organism, separate Mueller-Hinton agar plates were used in a sterile zone. All the inoculated plates were incubated at  $37^\circ\text{C}$  for 24 hours. The test plates were examined for the clear zone of inhibition around the finished fabrics. The zone of inhibition around each type of fabric specimen was measured in millimeter (mm).



### Antifungal activity – AATCC 30

The test specimens (coconut and pista charcoal finished Fabrics) were cut into pieces (50mm in diameter) and antifungal activity was tested using standard AATCC-30 test method. All the test cultures (*Candida albicans* and *Candida tropicalis*) were inoculated in a sterile Nutrient broth (Composition g/L: Peptone: 5g; Yeast extract: 5g, Beef extract: 3g, Sodium chloride: 5g; Final pH -  $6.8 \pm 0.2$ ) and allowed to attain the growth for 24 to 48 hours. Using sterile 4mm inoculating loop, one loop full of culture (*Candida albicans* and *Candida tropicalis*) was transferred by swabbing all around the surface of the Mueller-Hinton agar plate (Composition g/L: Acid hydrolysate of Casein: 17.5g; Starch: 1.5g, Sodium chloride: 5.0g, Agar 17.0 g; Final pH -  $7.0 \pm 0.2$ ) and also covering the central area of the petridish. For each test organism, separate Mueller-Hinton agar plates were used in a sterile zone. All the inoculated plates were incubated at  $37^\circ\text{C}$  for 24 hours. The inoculated plates were examined for the interruption of growth along the swabs of inoculum beneath the fabric and for a clear zone of inhibition beyond the fabric edge. The average width of the zone of inhibition around the test specimen calculated in millimeter (mm).

### Anti-odour test – Modified Artificial sweat studies (AATCC Test Method 15-2002)

In order to identify the efficiency of the charcoal finished fabrics on controlling the odour caused by test microorganisms (*Staphylococcus aureus* and *Micrococcus luteus*) artificial sweat studies was conducted. Artificial sweat was prepared as per the AATCC Test Method 15-2002 (Table-2) and pH was adjusted to 4.3. Odour causing bacteria *Staphylococcus aureus* and *Micrococcus luteus* were inoculated on the prepared artificial sweat separately and incubated for 24 hrs. About 2ml of the artificial sweat was sprayed on the test swatch. The samples were sealed in a petri dish to prevent oxidation. Then the odour intensity was determined by sensory evaluation. Ten subject persons were used for the evaluation and the odour was determined using the grades given in Table-3.

### Absorbency test - Wicking properties (AATCC TM 197)

The wicking properties of the coconut and pista charcoal finished cotton and bamboo fabric swatches in comparison with the control fabrics were investigated using AATCC TM 197 standard test method. Vertical Wicking of Textiles, is used to measure "the ability of vertically aligned fabric specimens to transport liquid along and/or through them" Wicking rate is a particularly important property that measures a fabric's ability to remove sweat/liquid from contact with the skin.

The wickability of the test fibres was evaluated by time for wetting. During the analysis, the fibre samples were conditioned in a standard atmosphere of 22°C under 65% relative humidity for 24 hours. The pre-measured size (1.5cm x 5cm) of each test mounted on the glass slides was kept at immersed condition inside a reservoir containing distilled water. The wicking height of the advancing liquid front as a function of time was recorded by visual observation after 5 minutes. Using a standard ruler scale, the colour of water absorbed on the fibre surface was measured for each sample and the values were recorded.

### Air-Permeability test (ASTM D 737-96 test method)

Air permeability of a fabric is the volume of air measured in cubic cm passed per second through 1 sq. cm for the fabric at a pressure of one cm. head of water. Air permeability can be measured using an instrument called Shirley Air Permeability Tester. Air permeability was determined in accordance with Test Method ASTM D-737-96. The conditioned specimens in the standard atmosphere for testing textiles,  $21 \pm 1^\circ\text{C}$  and  $65 \pm 2\%$  relative humidity was tested unless otherwise specified in a material specification or contract order. The test specimens (coconut and pista charcoal finished cotton and bamboo fabric swatches) were carefully handled to avoid altering the natural state of the material. Placed each test specimen onto the test head of the test instrument, and performed the test as specified in the manufacturer's operating instructions. Read and recorded the individual test results in SI units as  $\text{cm}^3/\text{s}/\text{cm}^2$ .

## RESULTS AND DISCUSSION

Charcoal is said to be an excellent absorbent. The main purpose of charcoal is that, it absorbs unpleasant odors. Activated charcoal is used in most of the fields due to its remarkable absorption and odour control properties that is of low cost and has better efficiency. Activated charcoal is a potent natural treatment agent as it is a universal antidote. It has a wide range of application ranging from medicinal values to industrial purposes. By burning materials like coconut shell, coal, sawdust, wood, bone char, petroleum coke, etc., fine black powder is formed resulting in activated charcoal. By the process of activating the charcoal, its surface area, internal structure and the pore size is been modified. The pore size of the carbon atom present in the activated charcoal is reduced due to this activation process exhibiting increased surface area. This activated charcoal is more porous hence it has good absorption properties than normal charcoal. The major advantage of activated charcoal is it does not cause any harm to humans as it does not contain any toxins (Mohan, 2020). The textile material finished with activate charcoal improves anti-microbial property of the fabric. The micro-organisms which come in contact with the fabric due to contact with skin, sweat, wounds or by any other means, an effective ant-microbial property against microbes like of *Staphylococcus aureus*, *Escherichia coli* and *Candida* species and other species was exhibited. In the present study the antimicrobial property of the coconut shell and pista shell charcoal finished fabric was determined. Other tests such as anti-odour test, vertical wicking test and air permeability test was observed to know the efficiency of the charcoal finished fabric.

**Antibacterial activity – Qualitative antibacterial activity**

The qualitative antibacterial activity test was performed and the following results were obtained. The table shows that charcoal finished fabric of cotton and bamboo showed good anti-bacterial property. The control (unfinished) fabric did not show any zone of inhibition. The coconut charcoal finished cotton fabric exhibited 30mm and 25mm zone of inhibition for *Staphylococcus aureus* and *Micrococcus luteus* respectively. For the cotton fabric finished with pista charcoal, the zone of inhibition was 31mm for *Staphylococcus aureus* and 27mm for *Micrococcus luteus*. (Table - 4, Fig. 1a and 1b). The zone of inhibition observed in bamboo finished with coconut charcoal was 29mm for *Staphylococcus aureus* and 26mm for *Micrococcus luteus*. The bamboo finished pista charcoal fabric presented about 28mm and 26mm zone of inhibition for *Staphylococcus aureus* and *Micrococcus luteus* respectively (Table - 4 and Fig. 1c and 1d).

With respect to (Pragadeeswari and Sangeetha, 2017) similar work such as the antibacterial property of the cotton and bamboo carbon finished fabric was carried out. The results obtained showed that zone of inhibition for direct application of charcoal to the cotton fabric was about 21mm for *Staphylococcus aureus* and 18mm for *E. coli*. Whereas the micro encapsulated carbon finished fabric showed better results with zone of inhibition 25mm for *Staphylococcus aureus* and 23mm for *E. coli*. In accordance to (Yang et al., 2009) the antibacterial efficacy of the Bamboo charcoal supporting silver BC/Ag composites with different concentrations against microbes was tested based on zone of inhibition tests. The zones of inhibition of the BC/Ag composites against *S. aureus* and *P. aeruginosa* ranged between 11.8 to 14.0 mm and from 10.8mm to 13.0 mm respectively. The BC/Ag composites exhibited significant efficacy against *S. aureus* and *P. aeruginosa*, and the efficacy increased with increasing Ag content. During the process of wearing the clothes, bacteria present in the skin attaches to the clothing and selective bacterial growth occurs. Sweat, sebum and bacterial metabolites are adsorbed by the clothing through contact with the skin and they serve as precursors for mal-odour formation (Klepp et al., 2016). These can be prevented by using anti-bacterial charcoal finished fabric that prevents the mal-odour formation resulting in the inhibition of bacterial growth in the fabric. (Thierry Le Blan and Arnaud Vatinel, 2018) stated that the activated charcoal has a good anti-microbial property and also controls odour while the fabric is finished with charcoal.

**Antifungal activity – AATCC 30**

The anti-fungal activity of the fabrics exhibited good zone of inhibition against microbes. The table displays that the control (unfinished) fabric has no zone of inhibition. For the coconut charcoal finished cotton fabric, zone of inhibition was observed as 61mm for *Candida albicans* and 58mm for *Candida tropicalis*. With 62mm and 58mm zone of inhibition for *Candida albicans* and *Candida tropicalis* respectively in cotton fabric finished with pista charcoal (Table - 5, Fig. 2a and 2b). The zone of inhibition resulted with 58mm for *Candida albicans* and 59mm for *Candida tropicalis* in bamboo finished coconut charcoal. The bamboo pista charcoal finished fabric showed 62mm and 61mm zone of inhibition for *Candida albicans* and *Candida tropicalis* respectively (Table - 5, Fig. 2c and 2d).

According to (Pragadeeswari and Sangeetha, 2017) similar work was carried out to determine the antifungal property of the cotton and bamboo carbon finished fabric. The charcoal finished fabrics of both cotton and bamboo showed good results against *Aspergillus niger*. The direct application of charcoal to cotton and bamboo fabric revealed 46mm and 49mm zone of inhibition respectively. The micro-encapsulated fabric of cotton and bamboo displayed zone of inhibition with 52mm and 54 mm respectively. The microorganisms are introduced through water, dirty laundry, sweat and human skin contact. The microbes survive and thrive through the biofilm formation and stagnant water. Microorganisms making up these biofilms include bacteria and fungi such as *Candida* species [(Nix et al., 2015) (Gattlen et al., 2010) (Babic et al., 2015)]. The microbes contact can be prevented by coating the fabric with activated charcoal which inhibits the microbial growth by interrupting in biofilm formation, thus providing anti-fungal activity.

### Anti-odour test - Artificial sweat studies

The anti-odour test for the charcoal finished cotton and bamboo fabrics was performed with odour causing bacteria *Staphylococcus aureus* and *Micrococcus luteus* in the present study. The fabrics were rated according to the odour scale between 1 to 5 attributing to 'no odour' to 'very unpleasant odour' respectively. The results presented that the control (unfinished) fabric with 5-very unpleasant odour. Whereas, the coconut charcoal finished cotton and bamboo fabric showed 1-no odour against both test organisms. But slightly not pleasant odour occurred in pista charcoal finished cotton and bamboo fabric against both test organisms. The anti-odour scale for each type of charcoal finished test fabrics against the odour causing agents was presented in Table-6.

As per (Pragadeeswari and Sangeetha, 2017) the odour-control assessment was carried out for the charcoal finished fabric cotton and bamboo. The fabrics were rated from the odour scale of 0-10 i.e., repulsive, very poor to ideal. An average rating was determined for the fabrics. The charcoal finished cotton and bamboo fabric applied in direct method showed the odour rating scale of 8-very good. Whereas, for the bamboo fabric micro-encapsulation finish showed odour rating scale of 7- good and the coconut fabric micro-encapsulation finish exhibited odour rating scale of 8- very good. Overall, carbon finished fabrics of both Cotton and bamboo gave good result. With respect to (Mohan and Durai, 2020) evaluation of odour control was performed. In this, the cotton fabric was finished on both sides with activated charcoal paste and the working professionals wore under the shoe insole and then the odour evaluation was recorded. On a grading scale of 0 (Repulsive) to 10 (Ideal) the evaluation was made. The charcoal finished fabric was tested for odour control in the subjects. On the odour rating scale of 10, an average range between 7 (good) to 8 (very good) was observed.

The odour intensity is mainly contributed by the clothing, since skin debris, secretions, odour volatiles, sebum and the micro-organisms in contact are transferred to the garment. The intensity of the odour was more intense potentially in the fabric substrate rather than adjacent axillae. The micro-organisms get attached to the fibers of the fabric and they use dirt or sebum compounds as substrate generating volatiles which are the by-products [(Munk et al., 2001) (Mc Queen et al., 2014) (Chung and Seok, 2012)]. Human sebum is the major compound that increases the load on the textiles. Some sebum components result in remnant of fatty components which remains on the fabric and forms a potential substrate for microbial growth and mal-odour formation. (Thierry Le Blan and Arnaud Vatinel, 2018) stated that the activated charcoal finished fabric has a good potential to control mal-odour and it is used as a functional material.

### Vertical wicking

The vertical wicking test was done for the unfinished and finished fabrics. The unfinished (control) cotton and bamboo showed between 2.1 to 2.3cm wicking height. The finished cotton pista charcoal and bamboo pista charcoal fabrics exhibited wicking height of 2.1cm. Whereas, the cotton coconut charcoal finished fabric resulted with 1.9cm wicking height and the bamboo coconut charcoal finished fabric revealed 2.0cm (Table-7). From the above analysis, it was confirmed that there was only a slight difference between the charcoal finished and unfinished control fabric with respect to wicking. This indicated that the charcoal finished for odour control property does not have any impact on the absorbency of the fabrics. The nativity of the fabric was not changed.

In accordance to (Gunasekaran et al., 2019) the wicking property of the control and the treated fabrics were tested by taking into account the time taken to reach six regular intervals of each 1 cm. The mean values of time taken in seconds for the treated and control fabric samples were determined. The treated fabric involved finishing of bamboo charcoal. The fabric type taken for the study was, cotton, polyester and blend of both. The overall improvement in wicking for 6 cm wicking height can be calculated which was found to be 147% (433 s), 100% (944 s) and 112% (256 s) with the bamboo charcoal particles treatment on cotton fabric, polyester fabric and the blend of both respectively. The wicking process can be related with the capillary action which is the transport of liquids by its own surface or interfacial forces in narrow tubes or voids (Sharabaty et al., 2008).

As the number of pores increases in the bamboo charcoal porous structure, the wicking property of the treated fabric improves due to the capillary action.

One of the important parameters to understand the wicking process is the mass increment caused by absorbed water. The increase in the wicking height in both weft and warp direction in the fabric, obviously increases the overall mass of water absorbed by the fabric. And also, with increase in the wicking height, decreases the mass increment per centimeter interval, indicating that the mass increment gradient at each 1cm interval becoming smaller (Cheng *et al*, 2002). This mechanism of action is due to the gravitational effect and the hygroscopicity of the fabric. In general, the moisture transport is said to be one of the main factors that influence the physiological comfort of the fabric, specifically in sportswear. While sweating occurs, because of the difference in concentration of the liquid molecules and difference in pressure on both sides of the clothes, they absorb the moisture and transfer it outside. In case, the clothes are not able to absorb the sweat within short interval or if the amount of sweat and perspiration is more than the capacity of absorption of the clothes, then there occurs and uncomfortable clothing (Cvelbar *et al*, 2009). The improvement in comfort of the textiles can be achieved by understanding mechanism of liquid transport. The moisture transport in the textiles can be expressed by a process called wicking which involves spontaneous transportation of liquid in to a porous system through capillary force that has often been used (Harnett and Mehta, 1984).

### **Air permeability**

The air permeability of the control (unfiniahed) and the charcoal finished fabric for cotton and bamboo was recorded. The coconut carcoal finished cotton fabric showed 24.3 cm<sup>3</sup>/cm<sup>2</sup>/sec while the unfinished fabric was 24.6 cm<sup>3</sup>/cm<sup>2</sup>/sec. Coconut carcoal finished bamboo fabric displayed 22.3 cm<sup>3</sup>/cm<sup>2</sup>/sec with control fabric 22.9 cm<sup>3</sup>/cm<sup>2</sup>/sec. About 23.6 cm<sup>3</sup>/cm<sup>2</sup>/sec and 21.3 cm<sup>3</sup>/cm<sup>2</sup>/sec height was recorded for the pista charcoal treated cotton fabric and bamboo fabric respectively while their control displayed 24.9 cm<sup>3</sup>/cm<sup>2</sup>/sec for cotton and 22.6 cm<sup>3</sup>/cm<sup>2</sup>/sec for bamboo treated fabric respectively (Table-8). No significant difference in the air-permeability was observed for the coconut and pista charcoal finished fabric sample (cotton and bamboo) when compared to unfinished control fabric (cotton and bamboo). This indicated that the finishing materials does not have any impact on the porosity of the fabrics. The nativity of the fabric was not changed.

Gunasekaran et al., (2020) has determined the mean values of air permeability of the treated and control fabric. The fabrics such as cotton, polyester and the blend of both fabrics were treated with bamboo charcoal. It was observed that, there was slight decrease in the air permeability in all the three charcoal treated fabrics. The reduction accounts for 24.57%, with the 100% cotton fabric, 12.11% for 100% polyester and 39.55% for p/c blended fabric. The presence of particles distributed across the surface of the fiber blocks the pores partially in the fabric with increased drag of the air passage finally resulting in overall air permeability.

### **CONCLUSION**

In the present study, the activated charcoal from coconut shell and the pista shell were used to coat the cotton and bamboo fabric. To conclude, the anti-bacterial, anti-fungal and anti-odour properties were evaluated and exhibited maximum for the charcoal finished fabrics. The absorbency tests such as vertical wicking and air permeability was also recorded and good results were observed for the charcoal finished fabric. Future studies can be done regarding the coating techniques of charcoal to the fabric and can be analyzed further. This charcoal finished fabrics has its application in coating the inner layer of caps or helmets that are used in the medical, industrial fields and also for frequent travelers. As these charcoal finished fabrics controls the odour causing metabolic activities of microbes, different types of caps shall be manufactured based on this property in near future. Today's trend is more on sustainable products as the youngsters and many people are already aware on it. Hence, these products are significantly considered as sustainable products. Also other types of waste materials shall be prepared as charcoal for finishing different types of fabrics. This study would be considered highly significant by providing an eco-friendly and sustainable products for different fields of applications.

**CONFLICT OF INTEREST**

Authors declare no conflict of interest

**Table-1: Finishing method – Pad dry dip-nip treatment method**

Fabric types	Charcoal types	
	Coconut	Pista
Cotton	Pad dry dip-nip treatment method	
Bamboo		

**Table-2: Preparation of artificial sweat**

S. No.	Chemical composition	Concentration(% (w/v))
1	Sodium chloride	1.0
2	L-Histidine	0.097
3	Manosodium Phosphate (NaH <sub>2</sub> PO <sub>4</sub> )	0.025
4	Disodium Hydrogen Phosphate (Na <sub>2</sub> HPO <sub>4</sub> )	0.1

**Table-3: Grades and their inference**

S. No.	Grades	Inference
		Artificial Sweat Studies
1	1	No odour formation
2	2	Not unpleasant
3	3	Slightly unpleasant
4	4	Unpleasant
5	5	Very unpleasant

**Table-4: Antibacterial activity – Qualitative antibacterial activity**

S. No.	Fabrics	Zone of inhibition (mm)			
		<i>Staphylococcus aureus</i>		<i>Micrococcus luteus</i>	
		Control	Finished	Control	Finished
1	CC	0	30	0	25
2	CP	0	31	0	27
3	BC	0	29	0	26
4	BP	0	28	0	26

CC: Cotton + coconut charcoal, CP: Cotton + pista charcoal

BC: Bamboo + coconut charcoal, BP: Bamboo + pista charcoal

**Table-5: Antifungal activity – AATCC 30**

S. No.	Fabrics	Zone of inhibition (mm)			
		<i>Candida albicans</i>		<i>Candida tropicalis</i>	
		Control	Finished	Control	Finished
1	CC	0	61	0	58

2	CP	0	62	0	58
3	BC	0	58	0	59
4	BP	0	62	0	61

CC: Cotton + coconut charcoal, CP: Cotton + pista charcoal

BC: Bamboo + coconut charcoal, BP: Bamboo + pista charcoal

**Table-6: Anti-odour test – Artificial sweat studies**

S. No.	Fabrics	Odour causing organisms			
		<i>Staphylococcus aureus</i>		<i>Micrococcus luteus</i>	
		Control	Finished	Control	Finished
1	CC	5	1	5	1
2	CP	5	2	5	2
3	BC	5	1	5	1
4	BP	5	2	5	2

1-No Odour 2-Not unpleasant 3-Slightly unpleasant 4-Unpleasant 5-Very unpleasant

**Table-7: Vertical wicking**

S. No.	Samples	Wicking height in cm	
		Unfinished	Charcoal finished
1	CC	2.1	1.9
2	CP	2.3	2.1
3	BC	2.2	2.0
4	BP	2.3	2.1

**Table-8: Air permeability**

S. No.	Samples	Wicking height in cm	
		Unfinished	Charcoal finished
1	CC	24.6 cm <sup>3</sup> /cm <sup>2</sup> /sec	24.3 cm <sup>3</sup> /cm <sup>2</sup> /sec
2	CP	24.9 cm <sup>3</sup> /cm <sup>2</sup> /sec	23.6 cm <sup>3</sup> /cm <sup>2</sup> /sec
3	BC	22.9 cm <sup>3</sup> /cm <sup>2</sup> /sec	22.3 cm <sup>3</sup> /cm <sup>2</sup> /sec
4	BP	22.6 cm <sup>3</sup> /cm <sup>2</sup> /sec	21.3 cm <sup>3</sup> /cm <sup>2</sup> /sec

**Fig. 1: Antibacterial activity – Qualitative antibacterial activity**

**1a. Cotton fabric finished with Coconut charcoal**

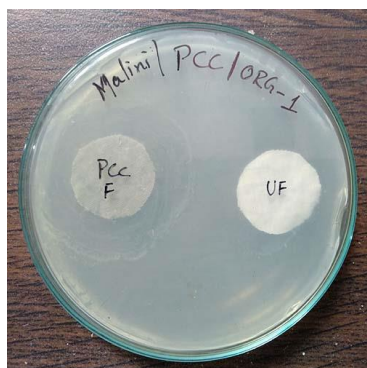


*Staphylococcus aureus*



*Micrococcus luteus*

**1b. Cotton fabric finished with Pista charcoal**



*Staphylococcus aureus*



*Micrococcus luteus*

**1c. Bamboo fabric finished with Coconut charcoal**



*Staphylococcus aureus*



*Micrococcus luteus*

**1d. Bamboo fabric finished with Pista charcoal**



*Staphylococcus aureus*



*Micrococcus luteus*

**Fig. 2: Antifungal activity**

**2a. Cotton fabric finished with Coconut charcoal**



*Candida albicans*



*Candida tropicalis*

**2b. Cotton fabric finished with Pista charcoal**



*Candida albicans*



*Candida tropicalis*

**2c. Bamboo fabric finished with Coconut charcoal***Candida albicans**Candida tropicalis***2d. Bamboo fabric finished with Pista charcoal***Candida albicans**Candida tropicalis***REFERENCES**

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