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Fluff pulp from straw of *Pennisetum glaucum* for hygiene applications

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The present study has been undertaken with two objectives, namely developing a laboratory test method to measure the absorbency of absorbent layers and investigating the properties and performance of pearl millet fluff (PMF) as an absorbent web of sanitary napkins using commercially available polypropylene and polyethylene as top and back layer respectively. The results indicate that the burette method, developed to test the absorbency of the absorbent layer of the napkin, is simple, effective, and reproducible. Further, the PM fluff used as an absorbent layer in sanitary napkins is an eco-friendly and economical source for this application.

Keywords: Absorbency test, Absorbent layer, Pearl millet, *Pennisetum glaucum*, Polypropylene, Polyethylene, Sanitary napkin

1 Introduction

India has a population of 1.34 billion, out of which 323.6 million are females in the age group of 15-49 years. Even if an estimated 121 million women in the menstruating age group used an average of 8 sanitary napkins (SN) every month, the total consumption would be staggering one million napkins per month[1]. This translates into a huge demand for raw materials for the production of hygiene products. While a sanitary napkin is typically made up of 3-4 layers, the most important layer is the middle absorbent layer. Nearly 70% of the total weight of a sanitary napkin is due to the fluff pulp in the absorbent layer, making it the most strategic material in these products. Desirable properties of fluff pulp include high absorption capacity, low absorption time and suitable fluid flow. Dry fluff cellulosic fibres obtained from pine wood pulp are generally used to produce this layer. Most countries, including India, import pine wood pulp for use in hygiene products. Over the past few years, however, there has been an interest in exploring locally available lignocellulosic materials, such as banana stalk[2], jute[3], bamboo[4], waste sorghum grains[5], milkweed fibre[6] and corn husk fibre[7] as potential substitutes for the expensive and imported pine pulp.

Pearl millet (*Pennisetum glaucum*) is a food crop grown abundantly in the states of Northern India. The coarse grain is used for food and the biomass is used as fodder. Due to the recent trend of using mechanical harvesters, a few inches of straw are invariably left in the ground after harvesting. To save time and labour costs, farmers burn this crop residue in the fields. Smoke from this burning crop residue is a major cause of air pollution in the Delhi National Capital Region (NCR) during the winter months of October-January. Finding alternate uses for the straw has, therefore, become an urgent need of the country. The aim of this study was to explore the possibility of producing fluff pulp from the residue of Pearl Millet Straw (PMS) and evaluate its suitability as a possible substitute for pine pulp in sanitary napkins. The performance of PMS fluff pulp was compared with that of pine fluff and a 50:50 mixture of PMS and pine fluff.

2 Materials and Methods

2.1 Preparation of Fluff Pulp from PMS

The dried stalks of PMS collected from the fields of Haryana state were washed thoroughly in running water to remove dust and other surface impurities and dried [Fig. 1 (a)]. Dried straw was treated with 1 M solution of NaOH (1:40 material- to- liquor ratio, 80°C, and 90 min) to remove the non-cellulosic components, such as hemicelluloses, lignin and proteins [Fig. 1 (b)]. The long fibres, obtained after delignification with alkali, were washed in water till the wash liquor showed a neutral *p*H. After this, the fibres were dried (90°C, 2 h) and chopped into 1-2cm length sections [Fig. 1 (c)].

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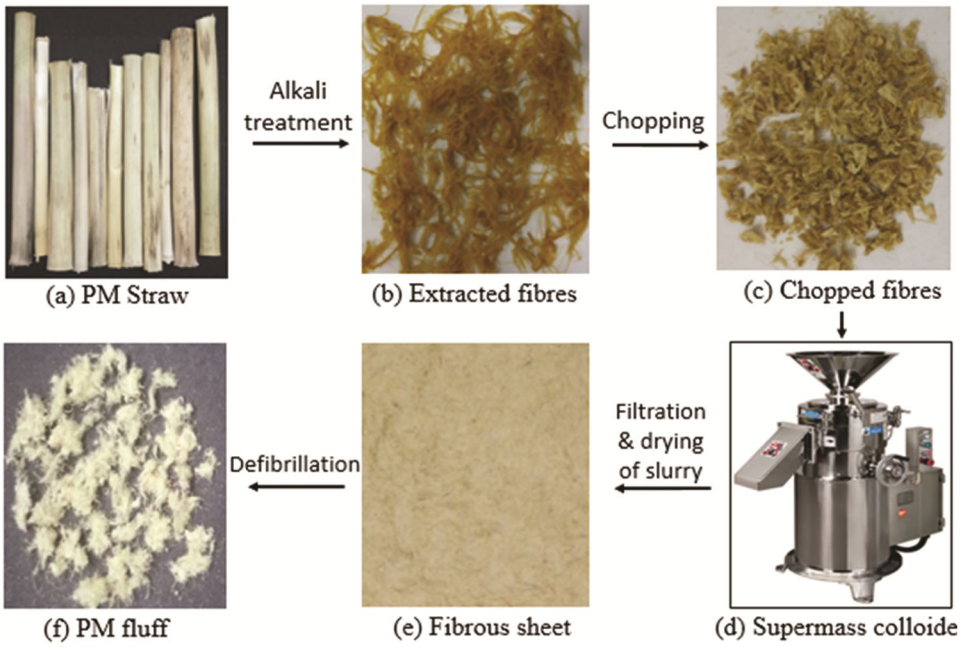

Fig. 1 — Extraction of PM fluff from PMS

A two-step grinding process was used to pulp the fibres. In the first step, 2 % (w/v) of chopped fibres were dispersed in water and ground coarsely in a mechanical stirrer (2000 rpm, 30 min). The slurry, thus produced, was fed into an ultra-fine friction grinder (Super Mass Colloider, Masuko Sangyo Co., LTD, Japan, Model: MKCA6-2J) [Fig. 1 (d)]. The SMC is based on the principle of passing the pulp slurry between two grinding stones, where one stone remains static and the other rotates. The disks are made up of non-porous ceramic material and have bursts and grooves that disintegrate the fibres into substructural components. The super mass colloider was operated at 1500 rpm and the sample was passed through it 20 times to make the pulp. The pulp was filtered through a nylon cloth and dried till a fibrous sheet of constant weight was obtained [Fig. 1 (e)]. The sheet was defibrillated (30 s) using a mixer grinder to convert it into dry fluff pulp [Fig. 1 (f)].

2.2 Characterisation of Fluff Pulp Fibres

PMS fluff fibres were prepared as mentioned in Section **2.1**. Pine fluff (commercial) was extracted from commercial sanitary napkins and a 50:50 mixture of the two types of fluff was prepared by mechanical mixing. The three samples (PMS fluff, pine fluff and 50:50 PMS/pine) were tested and characterised.

2.2.1 Length and Diameter

To determine the diameter of fluff fibres, they were observed under a scanning electron microscope (Carl Zeiss, EVO18, 20 Kev). The fibres were mounted on brass stubs and sputter-coated with gold. The average diameter was recorded by measuring the fibres at 30 different positions using Image J software. Since it was difficult to separate the fibres from each other due to their very short length, the length of fluff fibres could not be measured.

2.2.2 Density

The density of PM fluff was measured using the Davenport density gradient column. The column was prepared using carbon tetrachloride (density 1.59 g/cm^3) and n-heptane (density 0.68 g/cm^3), and it was calibrated with standard floats of known density. The calibration curve of height *vs* density was plotted. Five samples of PM fluff were put in the density gradient column in the form of tiny round balls and allowed to settle down in the column for 24 h before taking readings. The density of test samples was determined from their respective heights in the column, with the help of the calibration curve. The density of the mixed fluff fibres (50:50 PM/pine) was calculated using the following equation:

$$\rho_{mixture} = \frac{(m_1 + m_2)}{(v_1 + v_2)};$$

$$v_1 = \frac{1}{\frac{\rho_1}{m_1}} \; ; \; v_2 = \frac{1}{\frac{\rho_2}{m_2}}$$

where ρ_1 is the density (g/cc); and m_1, the mass (g) of PM fluff; and ρ_2 & m_2 , the density and mass of commercial fluff respectively.

2.2.3 Free Absorbency

For the fluff to be used as an absorbent in hygiene products, it is important to determine its absorption behaviour. Free absorbency is the absorption capacity of a sample when allowed to swell freely. Absorbency of fluff was tested for three fluids, namely DI water, saline, and artificial blood.

2.2.3.1 Preparation of Test Fluids

Three test fluids were used for testing the absorbency, namely deionized (DI) water, saline solution and artificial blood (Table 1). The stock solution of artificial blood was produced using the recipe proposed by Persin *et al.*[8] (Table 1). Hydroxyethyl cellulose (Tylose H 20 P 2) was used as a thickening agent, chloroacetamide (C_2H_4ClNO) as a preservative, glycerine to maintain the viscosity of artificial blood, and red dye and other chemicals to mimic the ionic nature of real blood. The stock solution, thus prepared, was as too viscous and hence it was diluted with DI water to bring the viscosity to 8 (Brookfield, RVDV –II+P). A *p*H meter (Oakton, AO-35423-01) was used to measure the *p*H of the solution. All chemicals used were of reagent grade (Sigma Aldrich). Nylosan Red dye was procured from Clariant Chemicals India Ltd.

2.2.3.2 Method for Testing Free Absorbency of Fluff Fibres

PMS fluff, pine fluff and a 50:50 mixture of the two were compared for absorbency performance. Test fibres (0.25 g each) were packed in a tea bag and placed in separate beakers, each containing 100 mL of the test fluid. Samples were removed after 10, 30, 60, 120, 180, 300 and 600 s and allowed to drain for 30s. The sample was weighed again to determine the wet mass. Free absorbency was calculated using the following equation:

Table 1 — Details of test fluids used in the study

Test fluids	Composition	Viscosity, cP	*p*H
DI water	-	1	7
Saline solution	0.9% NaCl	1.7	7
Artificial blood[8]	7% Tylose H 20 P 2 + 5% NaCl + 2% $NaHCO_3$+0.5% C_2H_4ClNO + 0.5% Nylosan red dye + 50% glycerine + DI water	8	7

$$Q_f(g/g) = \frac{W_2 - W_1}{W_1}$$

where Q_f is the free absorbency, W_1, the initial (dry) mass of the sample (g); and W_2, the final (wet) mass of the sample (g).

2.3 Preparation of Fluff Sheets

Three web samples were prepared using 100% PM fluff, 100% commercial or pine fluff and a 50:50 mixture of PM fluff and commercial fluff.

Circular samples of 5 cm diameter were cut for the absorbency test and rectangular samples 2.5 cm × 17 cm were prepared for the wicking test. For the absorbency test, a template was prepared by cutting out a circular cavity on a 5mm thick fibreboard sheet. One gram of fluff pulp was filled into the cavity, covered with a lid and pressed with a 2 kg load for 15 min. For the wicking test, a 2.5 cm × 17 cm cavity was cut out in the 5mm thick sheet and 1.5g of fluff was filled into the cavity and pressed with 2 kg load for 15 min.

2.4 Testing of Fluff Sheets

The absorbent sheets were characterised in terms of thickness, pore size, porosity, absorbency and vertical wicking.

2.4.1 Thickness

The thickness of a web is an important parameter affecting its absorbency. Thickness of test samples was measured under 2 gf/cm^2 load as per ASTM D1777-96 standard. Ten readings were taken at different locations and the average value was recorded.

2.4.2 Pore Size

Pores are void spaces, which are distributed throughout the volume of a porous medium. Pore size and pore size distribution are crucial parameters in evaluating the liquid absorption behaviour of any absorbent media. The pore size measurement of the test samples was done with the help of a Capillary Flow Porometer (Porolux 100 NW, IB-FT Germany). The porometer operates on the principle of displacement of an inert and nontoxic wetting liquid embedded in a porous material by applying an inert pressurised gas.

Test samples (2.5 cm in diameter) were immersed in the wetting liquid n-decane (0.850 mPa/s) for 40 s so as to fill all the pores. The saturated sample was extracted, placed and sealed, and then pressurised gas was passed through it. The flow of gas through the

sample, as the liquid is displaced out of the porous network was measured. The liquid moves out of larger pores initially, followed by the smaller pores of the wetted sample. The maximum pore diameter, smallest pore size and mean flow pore diameter (the pore size at which 50% of total gas flow can be accounted for, considering half of the flow is through pores larger than this diameter) the three test samples were recorded.

2.4.3 Porosity

Porosity is defined as the ratio of the total pore space in a medium to that of the total bulk[9]. It is one of the key factors in the design of industrially important absorbents as it determines the flow of fluid through the material. Porosity is affected by the packing density as well as the size and shape of particles in the media. The orientation of fibres in a fibrous media is another major consideration in porosity.

Liquid intrusion technique is a preferred method for measuring porosity of macro porous samples (pores of width>50nm), such as fibrous webs. A method proposed by Dhiman and Chattopadhyay[10], based on the use of n-decane as the test fluid, was used to estimate the porosity of the three fibre webs. Five circular samples of 5 cm diameter were cut out and their dry mass (W_d) was recorded. The volume of fibres (V_f) in each sample was calculated by taking the ratio of mass and fibre density. The samples were soaked in n-decane in a petri dish for 2 min and hung at an angle of 180° for 1 min. The mass of wetted samples was recorded (W_w). The mass of n-decane imbibed in the pores of the web (W_{nd}) is the difference between wet and dry mass (W_w–W_d) of the webs. Since n-decane is expected to occupy all the pores within the sample, the total volume of the pores (V_{nd}) in the sample was estimated by dividing the mass of n-decane by its density. The porosity of the sample was estimated using following equation:

$$\text{Porosity}\ (\%) = \frac{V_{nd}}{V_{nd} + V_f} \times 100$$

Packing density is the opposite of porosity. It is the ratio of volume of fibres covered in the sample over the total bulk volume of sample. Therefore, it was calculated as 1- porosity.

2.4.4 Vertical Wicking

Vertical wicking measures the rise of liquid in a sample against the force of gravity. This test determines the liquid transport properties of the porous media. In general, wicking takes place when a liquid travels along the surface of the media but is not absorbed by it. Wicking can only occur when a liquid wets fibres assembled with capillary spaces between them[11]. Wicking was measured according to the standard test method AATCC TM 197-2011. It determines the ability of the pad to transport the fluid along and/or through it against gravity at any given time. On a test sample (2.5cm × 17cm), markings were made at intervals of 1 cm from the sample's lower edge. The top end of the sample was clamped in a burette vertically and the other end was immersed in test fluid to a length of 1 cm. Acid Red 57 was added to the fluid for better visibility of the distance travelled by the liquid. The rate of fluid transport (distance per unit time) along the specimen was recorded at intervals of 1, 2, 3, 5, 10, 20 and 30 min.

2.4.5 Absorbency

A two-step burette test method was developed as part of this study to test the absorbency of absorbent layer (Fig. 2). The first step estimates the saturation absorbency of the sample in free state. The second step determines the fluid retained by the saturated sample under 1kg of load.

Test samples of 5cm diameter were cut out, conditioned (80°C for 30 min), weighed and used. Test fluids used were DI water, saline solution and artificial blood.

Step 1— Absorbency in Free State (A_f)

Absorbency in a free state, also known as saturation absorbency, is defined as the maximum amount of fluid absorbed by a material in a free state. For this test, the circular test sample was placed on a glass petri dish, over which a burette was positioned, keeping a distance of 1-2 mm between the sample and the burette (Fig. 2). The test fluid was dropped onto the centre of the sample from the burette at the rate of 15 mL/min till the point at which it just starts to flow out of the sample. This is taken as the saturation point of the sample for that fluid. At this point, the saturated sample was picked up with the help of tongs and placed on another petri dish which was kept inclined at an angle of 20° for one minute to allow the excess fluid to drain off. After this, the sample was weighed. Absorbency of the sample in free state (A_f) was calculated using the following equation:

$$Absorbency\ (A_f) = \frac{Saturated\ mass\ of\ sample\ (g)\ -\ Dry\ mass\ of\ sample\ (g)}{Dry\ mass\ of\ sample\ (g)}$$

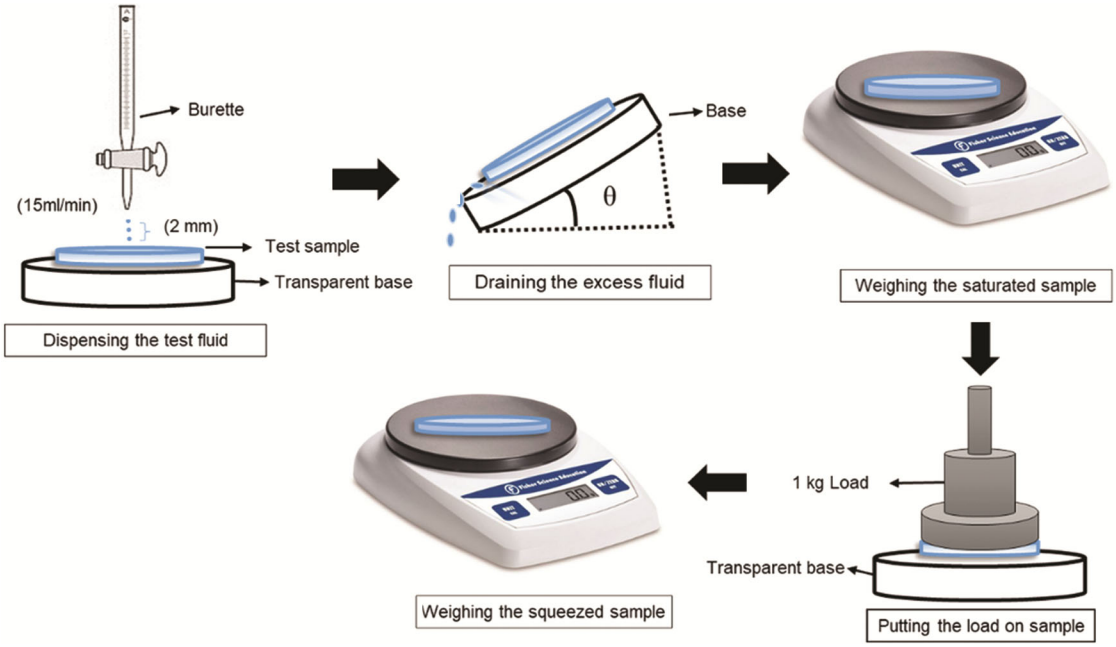

Fig. 2 — Schematic diagram of burette test method for measuring absorbency of fluff sheets

Step 2 — Fluid Retention Under Load (A_l)

Women are physically active and moving about during menstruating. Some of these activities exert pressure on the sanitary napkin and may cause leaking of fluid from the napkin. The second step, therefore, is designed to measure the volume of fluid retained in a saturated napkin under loading.

In this step, the saturated sample obtained from Step1 was placed on a glass surface. A weight of 1 kgf was kept over it for 1 min. The loading device was a circular stainless-steel load of 5 cm diameter. The diameter of the sample and the load was kept same so as to maintain uniform pressure (0.05 kgf/cm^2) on the entire sample. Excess water was released by the sample when it was loaded. The load was removed, and the sample weighed again. The fluid retained under load was calculated using the following equation:

$$\text{Absorbency } (A_l) = \frac{\text{Squeezed mass (g)} - \text{Dry mass (g)}}{\text{Dry mass (g)}}$$

2.5 Preparation of SN Samples

In the previous section, the sheet of fluff fibres was tested for absorbency properties. However, an actual sanitary napkin is made up of at least three layers. For this part of the study, three layered mini sanitary napkin samples of 5 cm diameter were produced by sandwiching the fluff layer between a polymeric top sheet (polypropylene) and a bottom (polyethylene) sheet. The top sheet is responsible for transporting the fluid to the absorbent layer and the bottom sheet is used to prevent leaking. Samples were prepared using 100% PM fluff, 100% commercial pine fluff and 50: 50 mixture of PM & pine fluff. These samples were tested for two tests, namely strikethrough and rewetting which are considered important in assessing the performance of a SN under actual conditions of use. All samples were tested in triplicate.

2.6 Testing of SN Samples

2.6.1 Wetting - Back Test

The wetting back of test napkins was assessed in accordance with Nonwoven Standard Procedure (NWSP 70.9) and (EDANA Guidelines for Testing Feminine Hygiene Products, 2018). The test examines the possibility of an absorbent layer to wet back the surface of a napkin under load. The method involves dropping a fixed amount of test fluid (3 mL) on the centre of the test sample (Fig. 3). As soon as the fluid was absorbed by the napkin, a disk of filter paper was placed on the surface layer and a mass of 1 kg applied on it for 1 min. The load stimulates the feminine body weight. The mass of fluid that is forced out of the absorbent layer and absorbed by the filter paper is recorded as the mass of wetback fluid.

2.6.2 Test for Liquid Strike Through

The test was carried out as per test standard NWSP 70.3 for nonwoven fabrics. A drop of the test fluids, blood and saline (2.5 mL), was allowed to fall on the sample from a dropper and the time taken for it to

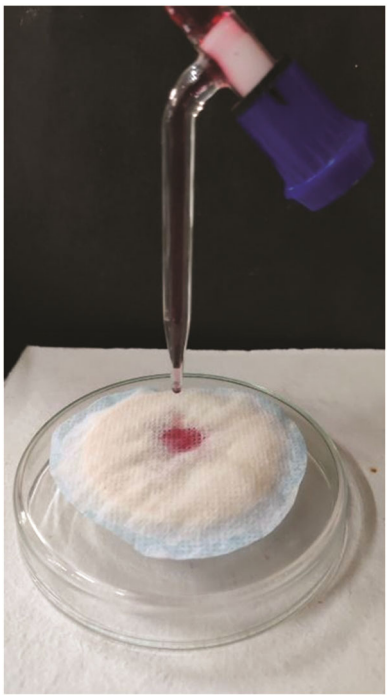

Fig. 3 — Wetting-back test of sanitary napkins

penetrate from the upper layer of the napkin to the outer most layer of the sample was recorded. The strike through was taken as the point at which a dull wet spot was detected visually on the lower layer of the sample. Strike through was estimated using saline and artificial blood as test fluids.

3 Results and Discussion

Properties of fluff fibres produced from PMS are compared with those of pine fluff and a mixture of PMS and pine fluff. Absorbent layers were prepared from fluff and tested. Sanitary napkin samples of 5 cm diameter were prepared with the three types of fluff fibres and tested. Results are presented and discussed hereunder.

3.1 Properties of Fluff Pulps

3.1.1 Morphology

The PM fluff fibres appear to be an entangled and non-uniform mass when examined through the electron microscope. The individual fibres have an average diameter of 9.26 ± 3.45 µm. The surface of PM fluff fibres is rough due to the presence of grooves and some deposits on the surface [Figs 4 (a) and (b)]. Pine fluff fibres are white in colour, have an average diameter of 26.45 ± 10.66 µm and have a smooth surface compared to PM fluff fibres [Figs 4 (c) and (d)]. The rough surface and yellow colour of PM fluff fibres [Fig. 1] indicates that some non-cellulosic components remain on the fluff fibres. These images indicate that the mechanical process of friction grinding used for producing the fluff is effective in reducing fibre size but is not effective in removing the non-cellulosic components from the fibres. Further chemical processing, such as bleaching, may be used to remove these impurities and improve their whiteness.

3.1.2 Density

The density of PM fluff and commercial fluff fibres is found to be in the similar range (1.49-1.53 g/cm^3) for PM fluff and (1.5-1.52 g/cm^3) for pine fluff.

3.1.3 Free Absorbency

Results of the free absorbency test are reported in Fig. 5. PMS fluff and pine fluff become saturated with saline after30s of wetting, and the saturation absorption value is 10.9 g/g and 12.6 g/g for PMS and pine fluff respectively. The mixture of fluff takes longer to saturate at 300s with a saturation absorption value of 14.2 g/g of saline. PM fluff absorbs a higher volume of blood (11.3g/g) as compared to saline, while the absorbency of pine fluff is similar for both fluids. The mixture absorbs less blood than saline, which may be due to the higher viscosity of blood (8 cP) as compared to saline (1.7 cP).

3.2 Testing of Fluff Sheets

Compacted circular sheets of 100% PM fluff, 100% pine fluff and a 50:50 mixture of the two were produced and characterised in terms of thickness, porosity, pore size, vertical wicking and absorbency (Fig. 6).

3.2.1 Thickness

One gram each of fluff fibres is packed into the template and then loaded to prepare compacted sheets with three types of fluff fibres. However, due to the different nature of the fluff fibres, the prepared samples have different thicknesses, that is 3.36 mm, 3.68 mm and 3.87 mm for PM fluff, pine fluff and mixture respectively. PMS fluff fibre is more compressible than pine fluff, while the mixture is the least compressible. The more compressible is a material, the more compactly it gets packed. A higher packing density generally indicates lower porosity and therefore lower absorbency.

3.2.2 Porosity

Porosity of an absorbent determines the amount of air it will trap or the amount of fluid it will hold. It can be determined from the ratio of total interstitial volume (voids) to the total volume of the specimen[12].

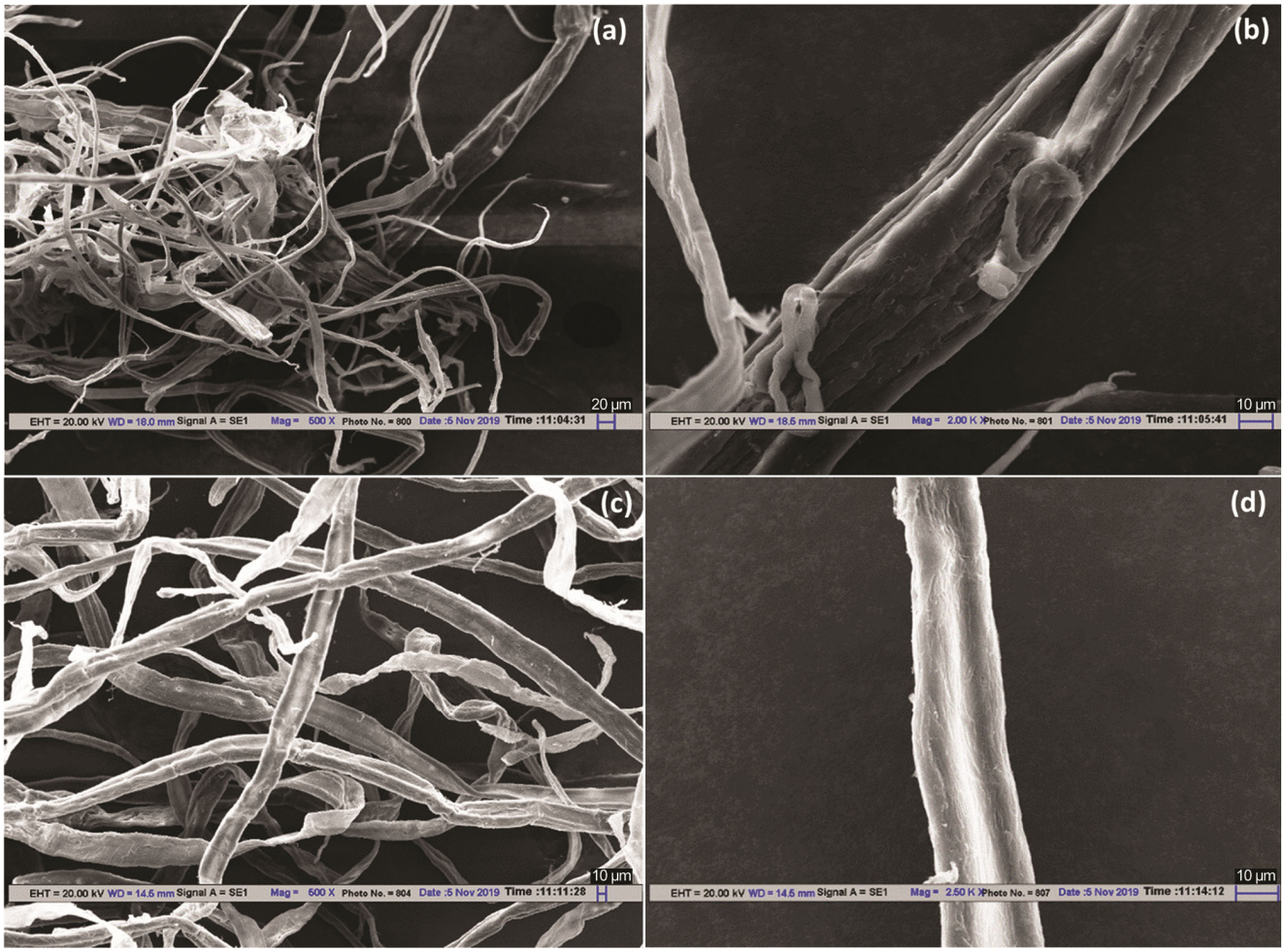

Fig. 4 — SEM micrographs of (a) pm fluff fibres, (b) magnified view of a pm fluff fibre, (c) pine fluff fibres, and (d) magnified view of a pine fluff fibre

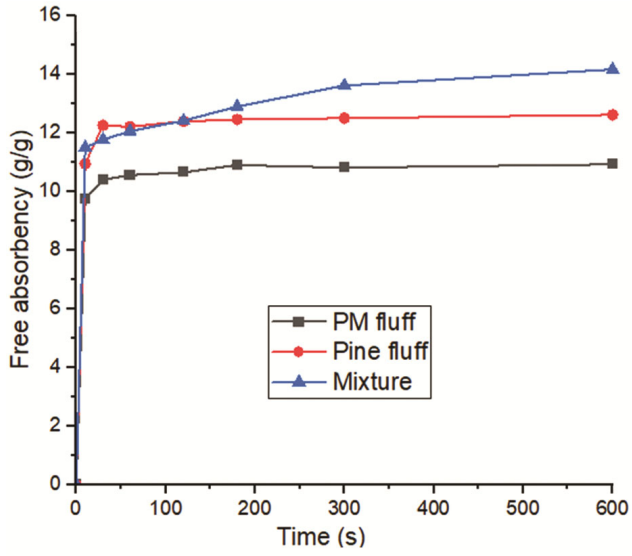

Fig. 5 — Free absorbency of fluff pulps for saline solution

Generally, the greater the porosity, the greater is the absorption capacity of the structure. Larger pore size leads to a higher rate of absorption for a given liquid contact angle[9]. Porosity decreases as the packing density increases because the number of fibres covering per unit area will be high which ultimately decreases the volume of pores present in that area.

The porosity and packing density of the test samples is shown in Table 2. The per cent porosity of test samples is similar for the three samples, varying between 93.58 (PMS) and 94.51 (mixture). The corresponding packing density of samples is found between 0.05 and 0.06.

3.2.3 Pore Size

Generally, the pores in a porous media have different sizes and are interconnected in a three-dimensional network and exert different capillary pressures[13]. Sometimes the pores are so small that

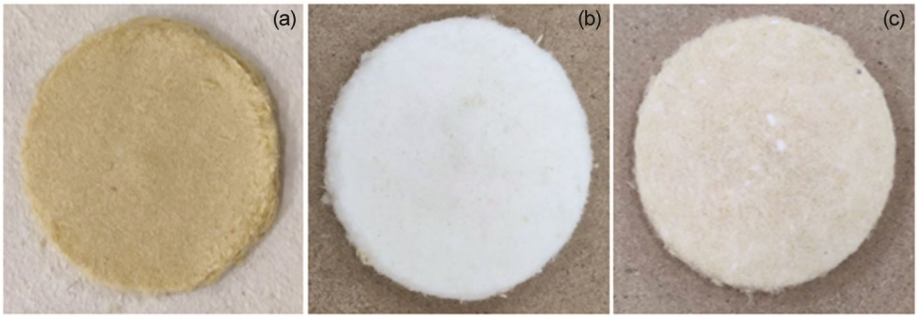

Fig. 6 — Compacted samples (a) 100% PM fluff, (b) 100% pine fluff, and (c) 50:50 mixture

Table 2 — Porosity of developed webs

Sample	Pore size distribution, µm		Porosity %	Packing fraction
	MFP	SP		
PM fluff	20.2	2.44	93.58	0.07
Pine fluff	23.91	3.07	94.23	0.06
Mixture	24.12	3.09	94.51	0.06

they act as traps and retard the flow of mass[9]. Thus, it is important to determine the mean flow pore (MFP) and smallest pore (SP) size of any sample. The MFP and SP of the test samples are given in Table 2. The web made from PM fluff has the lowest SP and MFP compared to samples of pine and mixture fluff. The pore size distribution (PSD) of the three samples is shown in Fig. 7. It can be seen that the frequency of small pores (2-10 µm) is highest in PM fluff web followed by mixture and commercial fluff web samples.

3.2.4 Vertical Wicking

The liquid absorption behaviour of absorbent media is primarily dictated by the phenomena of wetting and wicking. Wetting is the pre-requisite to wicking, and it is the first response of the fibre to a liquid system where the displacement of a solid–air interface with a solid-liquid interface takes place. On the other hand, wicking is the spontaneous flow of liquid through the capillary. If the forces of adhesion between the liquid and the pore wall (e.g. fibre surface) are greater than the forces of cohesion between the molecules of the liquid, then capillary motion occurs. Wicking in any porous media depends on the wetting behaviour of the absorbent media, the characteristics of the liquid used and the pore structure of the media[13].Liquid wicking in porous media is driven by capillary pressure, which is governed by the following Laplace equation:

$$p = \frac{2\sigma \cos \gamma}{R_c}$$

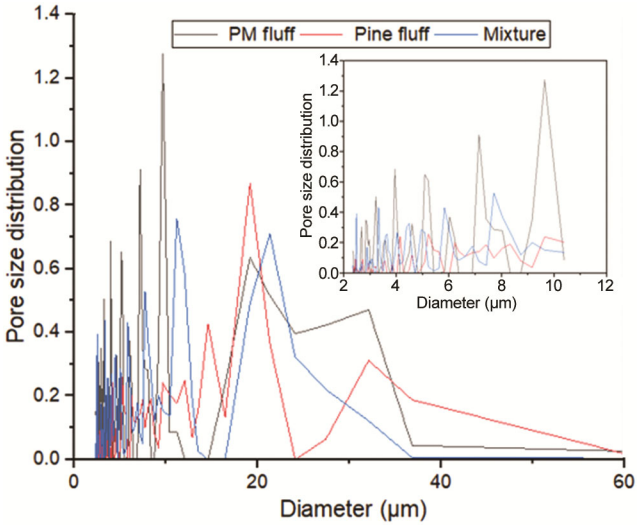

Fig. 7 — Pore size distribution of web samples

where R_c is the capillary radius; σ, the surface tension of the liquid; and γ, the contact angle at the liquid-solid-air interface. It means the finer is the capillary radius, the more is the wicking height[15]. Wicking is an important quality of sanitary napkins as they allow the blood to be distributed or spread throughout the pad while allowing the accumulated blood to be retained and distributed in the pad, thereby reducing leakage[16]. The wicking height results of developed absorbent webs are shown in Fig. 8. As seen from the graph, the rate of wicking is the highest for the mixture followed by pine fluff and PM fluff. This is due to the combined effect of pore size and the wettability of fluff. The wicking height of the mixture (50:50) web sample is greater than those of pine and PM fluff webs.

3.2.5 Absorbency

The sample comprising the mixture of fluffs shows the highest saturation absorbency followed by pine fluff and PM fluff (Table 3). In case of PM fluff, the average percentage decrease in saturation absorbency

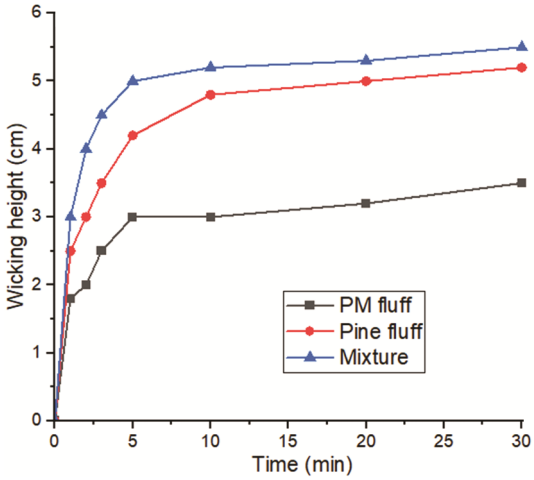

Fig. 8 — Wicking height of developed absorbent webs

Table 3 — Saturation absorbency of PM fluff, pine fluff and mixture

Sample	Saturation absorbency, g/g		
	DI water	Saline solution	Artificial blood
PM fluff	11.61	11.85	10.13
Pine fluff	13.56	13.02	12.59
Mixture fluff	13.89	13.82	12.94

on loading is 20%, 22% and 18% for water, saline and artificial blood respectively. However, in case of pine fluff & mixture samples, these values are 28%, 26-27% and 29% for water, pine fluff and blood respectively. It is observed that the absorption of artificial blood is slightly lower than saline and water in all the samples.

3.3 Testing of Sanitary Napkin Samples

The sanitary napkin samples have been prepared with top and back layers. The absorbent web samples (5 cm diameter) are sandwiched between a top layer (polypropylene) and a back layer (polyethene) to prepare samples of SN. These samples were then tested for rewet and strike-through properties.

3.3.1 Rewet Testing of Sanitary Napkin Samples

Rewet or wet back is an important test for a sanitary napkin to determine its ability to resist the transport of liquid back to the skin from the liquid that has already penetrated the cover stock and been adsorbed by the core layer. It assesses the quantity of liquid released by the napkin when pressure is applied to the product[16]. The SN made from PM fluff absorbent web shows the lowest wet back values, while the mixture SN sample (50:50 of PM and pine fluff) shows higher values.

3.3.2 Strike through Time

Strike-through time shows the time taken for the transportation of fluid from the top part of the pad to the inner absorbent layer of the pad (EDANA 2018). The PM fluff napkin shows strike-through times of 4s and 6s for saline and blood respectively. The time taken by the test fluid drop to penetrate the back layer of pine fluff and mixture napkin is 1.2/1.5 and 1.5/1.8 s for saline/blood respectively. Low strike-through time is desired in hygiene nonwoven applications to transfer liquid away from the skin quickly for maximum comfort and keep the skin feeling dry[15].

The absorbent webs made from 100% PM fluff, 100% pine fluff and their mixture (50:50) show interesting results. The web made from PM fluff has the lowest thickness (3.36 mm), indicating that it is the most compressible sample. This may be because, the PM fluff fibres are finer, having a diameter of 8µm as compared to commercial fluff (26 µm). The fibre diameter and packing density affect the pore size and porosity of fibrous porous media. Fibres have a lower diameter pack well, and therefore form structures with fine or small pores. The smaller pores reduce the overall porosity of the web, whereas a fibre having a larger diameter forms a structure with increased average pore size. This is because, during the packing of such fibres, the number of fibres per unit area will be less, lowering the total number of crossovers per unit area and thus increasing the average pore size[16]. This is corroborated by the fact that webs made from 100% PM fluff have a lower average pore size or MFP of 20.2 µm and the smallest pore size of 2.44 µm compared to pine fluff having an average pore size of 23.92 µm and the smallest pore size of 3.07 µm. The web made from a mixture of PM and pine fluff shows higher MFP and SP. However, when the load is applied to liquid-saturated webs, the one with larger pores could retain less liquid in comparison to a web with smaller pores. The amount of blood absorbed is lower as compared to water and saline, perhaps because of the higher viscosity of the former fluid.

The pore size is also found to affect the strike-through and rewet properties of sanitary napkins. The SN made from PM fluff shows the lowest rewet. This may be attributed to the smaller size of pores in the PM fluff, which retain more liquid when loaded.

4 Conclusion

The study shows that the properties of fluff pulp produced from PMS are similar to those of

commercial pine pulp. The absorbency of loose and compacted PMS pulp is similar to that of pine pulp. Mixing PMS pulp with pine pulp improves the performance of the absorbent layer to a significant extent. Sanitary napkins prepared from PMS pulp show satisfactory rewet and strike-through performance. Further chemical processing of PMS pulp may be carried out to improve its purity and whiteness. The study demonstrates that PMS can be used as an indigenous, cheap and sustainable source of fluff pulp for use in feminine hygiene products. Part or full substitution of imported pine pulp with this abundant agro-waste material can be a viable means of reducing the cost of the products and dependency on imported pulp. This research also adds to the knowledge base regarding the properties of Indian agro-waste products and their potential in industrial applications.

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