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Some studies on 100% banana parallel laid and 60:40% banana: polypropylene cross laid non-woven fabrics

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Abstract
Global trend towards sustainable developments have brought natural, renewable biodegradable raw material into the focus, but due to lack of technical knowhow, only a small fraction of these non-conventional fibres are harvested and utilized. In this study we have developed parallel laid 100% banana nonwoven fabric and cross laid banana/polypropylene (60:40) nonwoven fabric. Three varieties of banana fibers namely Mahalaxmi, Shrimanti and Graint Naine were used for needle punched non-woven fabric preparations. Analysis of physical properties is carried out in machine direction and cross direction. This paper concludes that cross laid nonwoven fabric show superior tensile properties as compared to parallel laid nonwoven fabric. Shrimanti fibre nonwoven fabric is stronger than Graint Naine and Mahalaxmi fibre nonwoven fabric for both the parallel laid and cross laid structure. Parallel laid Mahalaxmi banana nonwoven fabric and cross laid Graint Naine banana nonwoven fabric gives higher elongation% for machine and cross direction. Increased air permeability of cross laid (60:40) banana/polypropylene non-woven fabric observed than parallel laid 100% banana non-woven fabric. Parallel laid Graint Naine non-woven fabric showed higher air permeability than Shrimanti and Mahalaxmi parallel laid non-woven fabric. Bursting strength of parallel laid nonwoven fabric is higher, both in the machine as well as in cross direction than cross laid nonwoven fabric for three varieties of banana fibres. Shrimanti banana nonwoven fabric showed higher bursting strength for parallel laid and cross laid structure than Graint Naine and Mahalaxmi parallel laid and cross laid structure.

Keywords: Cross laid, Parallel laid, Shrimanti, Mahalaxmi, Graint Naine

Introduction

The rising concern for ecological preservation promotes the resources which are safe, biodegradable and recyclable. Natural cellulosic fibers have successfully proved their qualities in consideration to ecological and economic view of fiber materials. Natural fibers possess important advantages like low density, biodegradability, high specific strength and modulus, appropriate stiffness, lightweight, corrosive resistance, renewable character, surface reactivity, low cost, large availability, absence of associate health hazard. There are a number of fiber-giving-plants available in India which can be used for common applications, but many of these fibers are dumped as wastes, for lack of their technical knowledge. Among such non-conventional fibers like Banana, Sisal, Jute and Flax, Banana fibre is gaining importance and interest of researchers, due to its low cost and abundant availability.

Banana fiber comes in the category of bast fibers and produced from the waste part of banana plant. Banana is a tropical crop and developed well in temperature range of 15–35 °C with relative humidity of 75–85%.

Maitey and Singha (2012) et al. studied the influence of fiber arrangement on the tensile strength of non-woven fabric. Nonwovens (Maity et al. 2012) made from natural fibers and specifically jute fibers are more commonly used in almost all sectors of technical textile such as home textiles, geo-textile, agricultural textile, filter media, clothing, automobiles, industrial textiles, etc.

It was observed (Sengupta 2009) that the application of batching oil affects the bulk density of non-woven fabric. For jute nonwoven fabric (Roy and Ray 2005), if jute batching emulsion is applied on the web before needling, the higher tensile strength for fabric observed. The improved (Sengupta et al. 2008) tensile properties observed in wet condition of the same non-woven fabric that may be due to increased cohesion between the fibres and more compact structure in swelling and shrinkage. Initially (Roy and Ray 2005, 2009a) tenacity, initial modulus and work of rupture increases with increase in fabric weight, but further increase in fabric weight shows a reduction in initial modulus and work of rupture and no change in tenacity. Elongation at break reduces with increase in fabric weight, punch density and depth of penetration.

Bursting strength (Roy and Ray 2009b) of nonwoven fabric increases with increase in fabric weight, needle punch density and depth of needle penetration and for a further increase in the optimum value of needle density and depth of needle penetration, reduction in bursting strength observed. With the increase in fabric weight (Roy and Ray 2009a), bending modulus of nonwoven fabric increases, on the other hand bending modulus achieves maximum value with the increase in punch density and depth of needle penetration, but further increase in such density and depth of needle penetration reduces bending modulus. For fabric weight (Madhusoothanan et al. 1998), the study also shows the same trend for jute/viscose blend needle punched nonwoven fabric, but as the proportion of viscose, the fibre proportion increases with blend proportion the decrease in bending modulus observed.

Paul and Mukhopadhyay (1977) studied the thermal behavior of woolenised jute and other blended fiber non-woven fabric. Blending woolenised jute improved thermal insulation property when it was used with pineapple leaf and ramie fibre in blends (Sengupta et al. 1999). The effect of fabric weight (Debnath and Madhusoothanan 2011) and needle density on thermal resistance of jute/polypropylene blend needle punched fabric was analysed, an increase in thermal resistance observed to increase in fabric weight.

Sengupta (2009) analyzed the effect of process parameter on the water absorption behavior of non-woven fabric. Debnath and Madhusoothanan (2007) studied the effect of needle density, depth of needle penetration and fabric area density on compression property of jute nonwoven needle punched fabric. Sengupta et al. (2005) concluded that with the increase in fabric weight, punch density and depth of penetration, the initial reduction in compressibility in terms of thickness loss observed, but after attaining minimum value, the reduction in compressibility is more for further increase in these variables.

Air permeability of jute and jute blended non-woven fabrics were investigated by various researchers (Debnath and Madhusoothanan 2007; Roy and Ray 2005). Parikh et al. (2011) analyzed the effect of process parameter on the sound insulation of non-woven fabric and Thilagavathi et al. (2010) expressed the behavior with needle penetration and sound loss of non-woven fabric.

The present work deals with physical studies of three varieties of banana fiber (Shrimanti, Graint Naine, Mahalaxmi) nonwoven fabric made of stem banana fibres. The physical parameters like thickness, gram per square meter, tensile properties, air permeability, bursting strength and bending length are discussed. A comparison of physical properties of three varieties of banana non-woven fabric of parallel laid and cross laid is discussed.

Methods

Three varieties of banana fibres, namely Mahalaxmi, Shrimanti and Graint Naine were selected as raw materials for this study, these three varieties were extracted from Krishi Vidnayan Kendra, Pal, Maharashtra, India.

Extraction process of banana fibre

Extraction of banana fibres was carried out on mechanical extractor (Fig. 1 banana fibre decorticator). Mechanical extractor/decorticator consist of a pair of the guide roller, feed roller, a beater having 14 to 16 blades, a deflecting blade, delivery roller and a waste collection chamber. Stem of the banana plant contains 6 to 8 layers and banana fibres can be extracted from first 4 to 6 layers only. By using a knife, longitudinal slices were prepared from the pseudo stem. These slices were manually fed to guide roller. With the

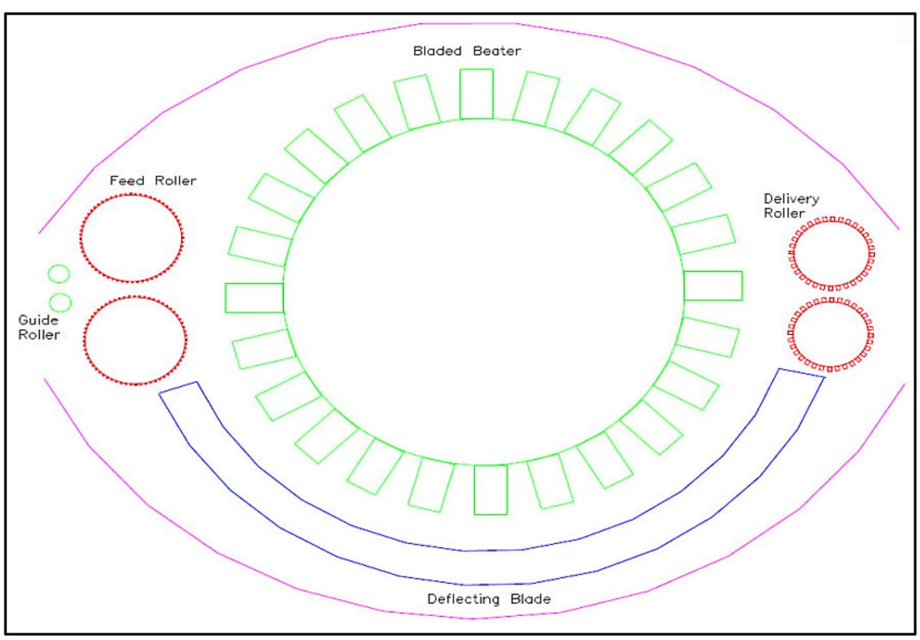


Fig. 1 Line diagram of banana fiber extractor machine (decorticator)

Table 1 Tensile property of banana fibres

Shrimanti stem fibre			Graint Naine stem fibre			Mahalaxmi stem fibre		
Linear density (Tex)	Tenacity (g/Tex)	Elongation (%)	Linear density (Tex)	Tenacity (g/Tex)	Elongation (%)	Linear density (Tex)	Tenacity (g/Tex)	Elongation (%)
7.5 [18.45]	88.20 [25.39]	3.1 [24.88]	6.5 [26.6]	76.60 [24.05]	3.1 [21.03]	5.84 [24.34]	69.40 [21.08]	1.85 [24.37]

Values in bracket indicate C.V. %

Table 2 Process parameter for non-woven needle punching

S. no.	Variable	Value
1.	Stroke/min	200
2.	Needle loom feed	0.90 m/min
3.	Needle loom delivery	1.01 m/min
4.	Needles/cm of width	40
5.	Stitch density/cm	90
6.	Advance/stroke	4.5 mm
7.	Feed lattice speed	0.40 m/min
8.	Doffer speed	19.90 m/min
9.	Cross lapper speed	20.20 m/min
10.	Feed in card	600 g/m^2
11.	Punch density	80

help of feed roller, the slices were feed to the rotating beater. The gap in between beater and the deflecting blade was kept in such a way that pulpy materials can be removed and banana fibres get separated from the stem. These extracted fibres surround more amount of pithy material. Hence to remove this pithy material squeezing followed by repeated combing was carried out. These extracted banana fibres were then air dried in the shade.

Tensile properties of banana fibers

The tensile properties were measured on Instron (model 4301) machine. The gauge length used for the test was 100 mm and the jaw speed maintained during testing was 300 mm/min. For each sample 20 observations were taken. The average force required breaking and breaking elongation were recorded. The tenacity values were reported in g/tex as shown in Table 1.

Banana non-woven fabric manufacturing

Needle punched banana nonwoven fabrics were manufactured using DILO needle punching machine. Table 1 displays the banana fiber properties and Table 2 displays the process parameters kept on needle punching machine for manufacturing of banana fibre needle punched nonwoven fabric.

Before manufacturing of nonwoven fabric 3–4 layers of fibres were prepared and conditioning of banana fibres was carried out for 24 h with emulsification as given in Table 3.

Table 3 Emulsification concentrations

S. no.	Ingredients	Quantity (%)
1.	Water	73
2.	Mineral oil (Jute batching oil)	25.4
3.	Emulsifier	1.6

These layers of fibres were processed through softener machine for softening of banana fibres and then carding of banana fibres was carried out on breaker jute carding machine. After carding the 100% banana fibers web was fed to needle punching machine and 100% parallel laid (P.L.) banana non-woven fabric was prepared. The cross laid (C.L.) non-woven fabric was prepared by mixing 60:40% of banana fibres with polypropylene fibres and these carded web was fed to needle punching machine for preparation of 60:40% cross laid banana: polypropylene non-woven fabric.

Non-woven fabric testing

The thickness of non-woven fabric was tested with ASTM D 5729-97 standard. The tensile properties of non-woven fabric measured according to ASTM standard D 5034. The gram per square meter of fabric was measured by preparing the sample on GSM cutter and weighing it on electronic weighing balance. The GSM of non-woven fabric tested with ASTM D 3776-96 standard. EPI and PPI were measured on one inch pick glass. The crease recovery angle of fabrics was tested on Shirley crease recovery tester. The rectangular specimen of size $2'' \times 1''$ was prepared and crease recovery angle in degrees were measured. The bending length of fabrics was tested on Eureka stiffness tester. The stiffness of non-woven fabric tested according to ASTM D 5732-95 standard. The air permeability of the fabric was measured on FX 3300 Air permeability tester. The air permeability of non-woven fabric tested in accordance with ASTM D 737-96 standard. The bursting strength of fabric measured on Eureka bursting strength tester. The bursting strength is tested in accordance with ASTM D 3786-87 standard for non-woven fabric.

Statistical analysis

An experiment in which all possible combinations are realized is called as full factorial experiment. Therefore N = Sk where N is the number of trials, k is the number of factors and S is the number of levels for each factor. Statistical design selected for this study was mixed factorial design of experiment and result evaluated.

Result and discussion

Tensile properties of parallel laid nonwoven fabric

Figures 2, 3 exhibits the breaking load and elongation at break of different banana fiber needle punched nonwoven fabric. It is evident from Figs. 2, 3 that tensile strength of Shrimanti P.L. nonwoven fabric is higher in comparison with Graint Naine and Mahalaxmi nonwoven fabric in both machine direction (M.D.) as well as cross direction (C.D.). This may be due to the higher tenacity of Shrimanti fibers (Table 1) compared to Graint Naine and Mahalaxmi banana fibers which contributing for greater tensile strength of Shrimanti non-woven fabric, while Graint Naine pararallel laid banana non-woven fabric

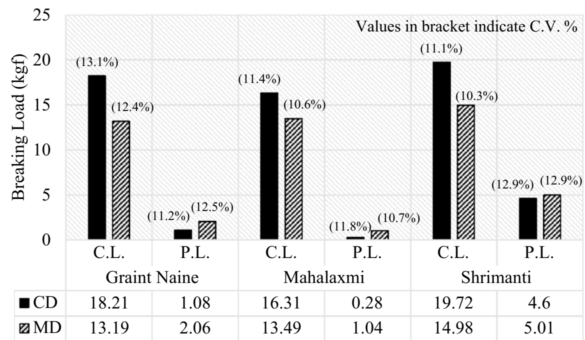


Fig. 2 Breaking load

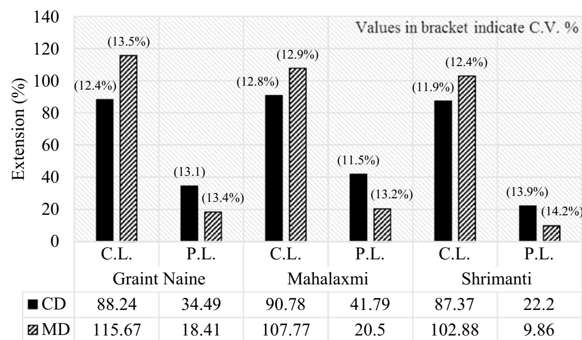


Fig. 3 Elongations (%)

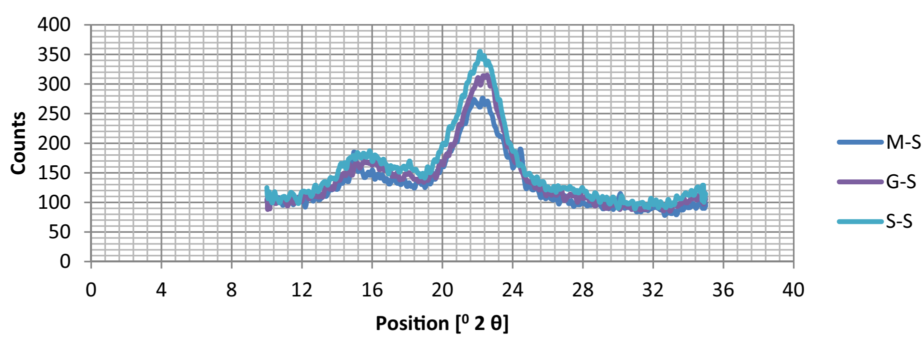


Fig. 4 X-ray diffraction (XRD) studies of banana fibers

shows higher tensile strength than Mahalaxmi non-woven fabric. As from the X-ray Diffraction (XRD) study (Fig. 4) of banana fibers it has been observed that crystallinity of Shrimanti fiber is 52.38%, which is higher in comparison with Graint Naine fiber 52.11% and Mahalaxmi 50.72%. The higher crystallinity of Shrimanti fibers may be contributing higher strength for Shrimanti fibers than Graint Naine and Mahalaxmi fibers.

P.L. Mahalaxmi nonwoven banana fabric shows higher elongation % compared to Graint Naine and Shrimanti nonwoven banana fabric in C.D. Whereas, P.L. Graint Naine nonwoven banana fabric shows higher elongation % than Mahalaxmi and Shrimanti nonwoven banana fabric in M.D. Higher tensile strength in the M.D. can observed compare to C.D. for all three varieties of P.L. nonwoven fabric. In P.L. non-woven fabric majority of fibers are oriented in M.D. of fabric. Hence, for the tensile test in M.D. of the fabric, the fibers can easily be reoriented much closer to the test direction, but if the testing is carried out in C.D. the majority of the fibers cannot be oriented in the test direction. Hence the contribution of fibers towards the load bearing is much higher in the testing of M.D. than in the C.D.

Statistical analysis (Table 4) reveals that there is no significant effect of variety of banana fibre as well as direction of test on breaking load as well as elongation of 100% P.L. nonwoven banana fabric. However, there is significant effect on type of fabric i.e. type of layup (P.L. or C.L.) on tensile properties of 100% P.L. nonwoven banana fabric.

Tensile properties of cross laid (60:40) nonwoven fabrics

Figures 5, 6 displays the tensile properties of C.L. banana/polypropylene (60:40) needle punched nonwoven fabric. It can be easily seen from Fig. 4 that tensile strength of Shrimanti C.L. nonwoven fabric is higher than Graint Naine and Mahalaxmi nonwoven fabric in both direction i.e. M.D. as well as in C.D., this may be because of the stronger behavior of Shrimanti banana fibers compared to Graint Naine and Mahalaxmi fibers (Table 1). Graint Naine nonwoven fabric shows higher elongation (%) than Mahalaxmi and Shrimanti nonwoven fabric in the M.D., while Mahalaxmi nonwoven banana fabric shows higher elongation % than Graint Naine and Shrimanti nonwoven banana fabric in the C.D.

Higher tensile strength in the C.D. is observed than in M.D. for all C.L. nonwoven fabric samples. This happens mainly because in C.L. nonwoven fabric, majority of fibres are oriented in C.D. than in M.D. and due to orientation of fibre in the direction of application of load, the contribution of fibres towards the load bearing is much higher in the C.D. than in M.D. for C.L. nonwovens.

As shown in Fig. 2, the tensile strength of C.L. banana/polypropylene (60:40%) nonwoven fabric were higher compared to P.L. 100% banana non-woven fabric for all three varieties of banana fibers, this may be due to the combine contribution of polypropylene fibers with banana fibers in load bearing capacity of non-woven fabric, resulting in higher tensile strength for C.L structure than P.L. structure.

Statistical analysis (Table 4) reveals that there is no significant effect of variety of banana fibre on tensile properties of C.L. banana/polypropylene (60:40) needle punched nonwoven fabric. Whereas there is significant effect of test direction on tensile properties of C.L. banana/polypropylene (60:40) needle punched nonwoven fabric.

Air permeability of nonwoven fabric

Air permeability of P.L. as well as C.L. banana nonwoven fabric is exhibited in Fig. 7. It can be observed from Fig. 7 that P.L. Graint Naine nonwoven banana fabric shows higher air permeability compared to Shrimanti and Mahalaxmi P.L. nonwoven banana fabric. While for C.L. structure Shrimanti non-woven fabric shows higher air permeability. This may happen because of the more variation in the linear density of the banana fibers (Table 1). C.L. nonwoven fabric shows higher air permeability compared to P.L. nonwoven banana fabric for all three varieties of banana fibres. P.L. fabrics have lower

Table 4 Statistical Analysis for P.L. and C.L. non-woven fabric

Source	Level	Breaking load		Elongation %		Air permeability	Bursting strength	Thickness	Bending length	Areal density
		P-value (PL)	P-value (CL)	P-value (PL)	P-value (CL)	P-value	P-value	P-value	P-value	P-value
Banana fiber variety	3	0.075	0.087	0.530	0.471	0.383	0.004	0.281	0.023	0.301
Fabric type	2	0.000	NA	0.000	NA	0.167	0.058	0.301	0.000	0.340
Test direction	2	0.129	0.026	0.823	0.033	0.000	0.016	0.701	0.661	0.239

If P-Value < 0.05 then it is statistically significant

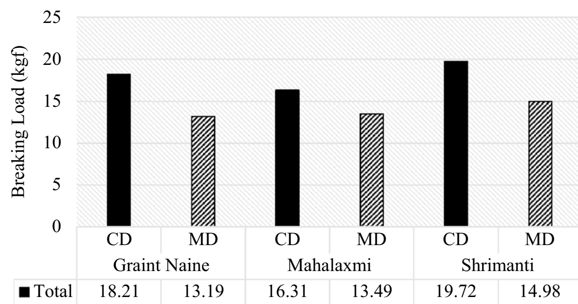


Fig. 5 Tensile strength of cross laid (60:40) banana nonwoven fabric

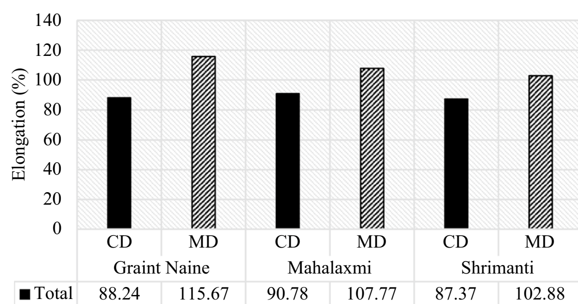


Fig. 6 Elongation % of cross laid (60:40) banana nonwoven fabric

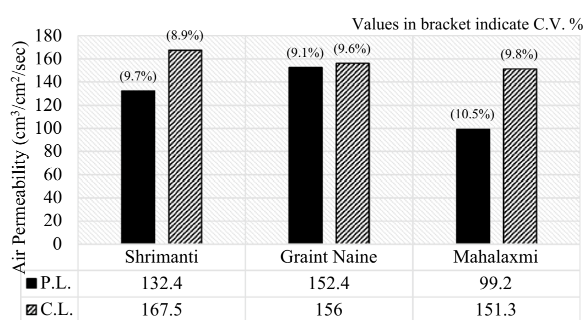


Fig. 7 Air permeability

values of air permeability than C.L. fabrics because the arrangement of fibres in P.L. fabrics make the fabric structure more compact so that it hold less air and offers more resistance to the flow of air.

Bursting strength of nonwoven fabric

Figure 8 shows bursting strength for P.L. and C.L. of all three varieties of banana fibre nonwoven fabrics. It can be observed that Shrimanti banana nonwoven fabric shows higher bursting strength in the M.D. than Graint Naine and Mahalaxmi for both P.L. and C.L. nonwoven fabric. This may be due to the incorporation of stronger behavior of Shrimanti banana fibers (Table 1) in comparison with Graint Naine and Mahalaxmi fibers.

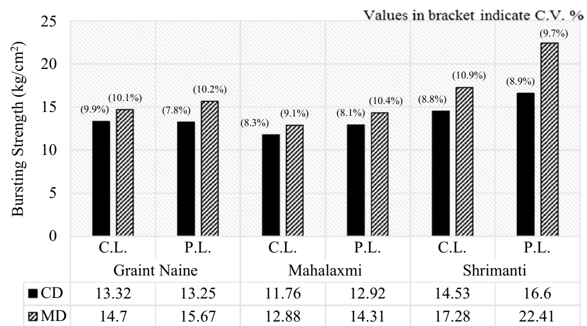


Fig. 8 Bursting strength

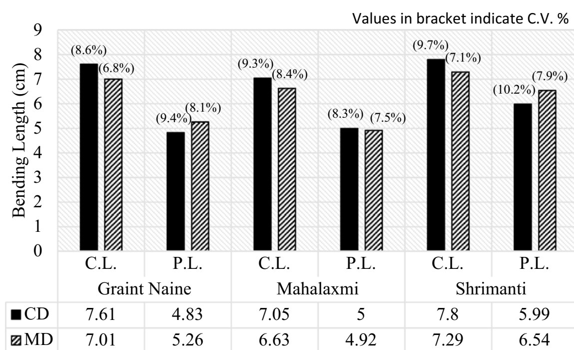


Fig. 9 Bending Length

The C.L. nonwoven fabric shows lower bursting strength compared to P.L. fabric for all three varieties of banana fibre nonwoven fabric in the M.D. as well as in C.D. More regular P.L. non-woven fabric structure may be contributing for higher bursting strength in comparison with C.L. structure. From the statistical analysis (Table 4) it can be observed that banana fiber variety have a significant effect on bursting strength of non-woven fabric. Banana fabric type (P.L. structure and C.L. structure) have a significant effect on bursting strength of non-woven fabric and test direction i.e. M.D. and C.D. have a significant effect on bursting strength of non-woven fabric.

Bending length of nonwoven fabric

Figure 9 displays the bending length of banana nonwoven fabric. It can be seen from Fig. 9 that bending length of P.L. as well as C.L. Shrimanti banana nonwoven fabric is higher compared to Graint Naine and Mahalaxmi both in M.D. as well as in C.D. This may be due to the stiff nature of Shrimanti banana fibers than Graint Naine and Mahalaxmi fibers. While Graint Naine non-woven fabric shows higher bending length values compared to Mahalaxmi non-woven fabric.

C.L. fabric shows higher bending length for all three varieties of banana fibre nonwoven fabric than P.L. fabric. As fiber orientation is more in the C.D. and high compactness of C.L. structure are responsible for giving higher bending length in C.D. than in M.D.

From the statistical analysis (Table 4) it can be observed that banana fiber variety does not have significant effect on bending length of non-woven fabric. Fabric type has a significant effect on bending length of non-woven fabric.

Thickness of nonwoven fabric

Higher thickness for P.L. fabric in the M.D. than in C.D. is observed for Shrimanti and Graint Naine nonwoven fabric, but a reverse trend is observed for Mahalaxmi fibre nonwoven fabric, this may be happen because of the higher variation of linear density (Table 1) for all three varieties of the banana fibers. It can also be observed from Fig. 10 that the P.L. structure non-woven fabric shows higher thickness than C.L. structure non-woven fabric, this may be due to the more regular structure of P.L. non-woven fabric making it thicker than C.L. non-woven fabric.

Areal density of nonwoven fabric

Areal density of P.L. and C.L. structure for three varieties of banana fibre can be observed from Fig. 11. Areal density of all the fabric samples was measured in g/m^2 (GSM). No significant difference for areal density of all three varieties of banana non-woven fabric can be seen from Fig. 11, for P.L. and C.L. structure.

Statistical analysis (Table 4) reveals that there is no significant effect of variety of banana fiber, type of nonwoven fabric and direction of test on areal density of banana needle punched nonwoven fabric.

Conclusions

This study carried out on the three different varieties of banana fiber to give insights about comparative analysis of non-woven fabric. Shrimanti fibre nonwoven fabric is stronger than Graint Naine and Mahalaxmi fibre nonwoven fabric for both the P.L. and C.L. structure. Banana fibre, C.L. nonwoven fabric shows superior tensile properties as compared to P.L. nonwoven fabric. P.L. Mahalaxmi banana nonwoven fabric and C.L. Graint Naine banana nonwoven fabric gives higher elongation% for machine and

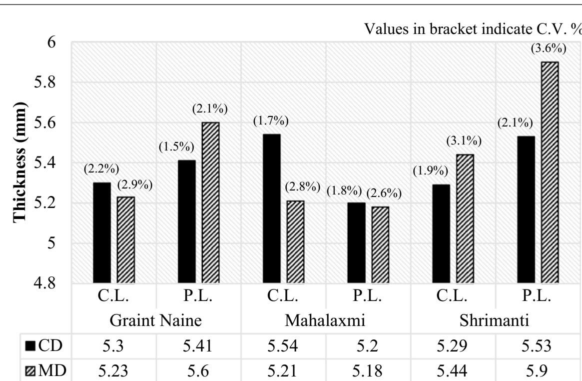
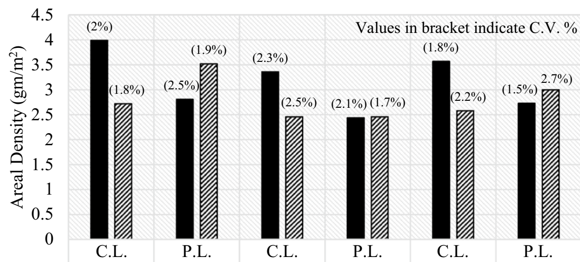


Fig. 10 Thickness exhibits the thickness of different varieties banana nonwoven fabric for P.L. and C.L. structures



	Graint Naine		Mahalaxmi		Shrimanti	
	C.L.	P.L.	C.L.	P.L.	C.L.	P.L.
■ CD	3.99	2.81	3.36	2.44	3.57	2.73
▨ MD	2.72	3.52	2.46	2.46	2.58	3

Fig. 11 Areal density

cross direction. Increased air permeability of C.L. (60:40) banana/polypropylene blend non-woven fabric observed than P.L. 100% banana non-woven fabric. P.L. Graint Naine non-woven fabric showed higher air permeability than Shrimanti and Mahalaxmi P.L. non-woven fabric. Shrimanti C.L. (60:40) banana/polypropylene non-woven fabric showed higher air permeability than Graint Naine and Mahalaxmi C.L. non-woven fabric. Bursting strength of P.L. nonwoven fabric is higher, both in the machine as well as in cross direction than C.L. nonwoven fabric for three varieties of banana fibres. Shrimanti banana non-woven fabric showed higher bursting strength for P.L. and C.L. structure than Graint Naine and Mahalaxmi P.L. and C.L. structure. P.L. structure non-woven fabric shows higher thickness than C.L. Areal densities remain same for all the nonwoven fabric samples. Bending length of the C.L. banana nonwoven fabric is higher than the P.L. nonwoven fabric. P.L. as well as C.L. Shrimanti fibre nonwoven fabric samples have more bending length than Graint Naine and Mahalaxmi nonwoven fabric. C.L. nonwoven fabric shows higher air permeability compared to P.L. fabric.

Authors' contribution
VSS carried out the research work. All the sample preparation, testing of samples and result and discussion completed by VSS and SM. Both authors read and approved the final manuscript.

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Competing interests
Author Vijay S. Shivankar and Samrat Mukhopadhyay have bear all the expenditure required for completion of the research work. This work we have not published anywhere earlier. This work is completely done by me (Vijay S. Shivankar) and my co-author (Dr. Samrat Mukhopadhyay). No one can give any claim for the submitted work.

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