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Comparison of mechanical and comfort properties of natural fiber-based spacer fabrics for shoe insole

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ABSTRACT

The objective of this study is to develop an improved shoe insole that enhances heat and moisture transmission (thermo-physiological comfort) qualities, as well as its mechanical characteristics, through the utilization of weft knitting spacer fabric. Two samples were prepared. One sample was comprised of Tri-Blend knitted fabric layers, while the other sample was made using cotton knitted fabrics in both layers. These layers, in both samples, were connected by spacer yarns of monofilament nylon. Tri-blend fabric was made from Bamboo (80%), flax (15%), and polypropylene (5%). Monofilament nylon was used in spacer layer. Thermo-physiological comfort testing i.e., air permeability, moisture management and thermal resistance test were performed for all the samples. The investigation also established the correlation between the mechanical properties, such as puncture resistance and tactile comfort, of footwear materials and their interaction with the human body. The prepared samples of shoe insole were also compared with the commercially available insoles made from synthetic materials. The outcome of the study suggests that the natural fiber spacer fabric can be used as an alternative to rubber. In conclusion, the results of this study offer valuable insights for product developers seeking sustainable alternatives that can meet consumer demands for both wearability and comfort.

1. Introduction

The insole is the inner lining of the shoe that runs under the plantar surface of foot and supports it. Insoles are also known as foot beds, inserts, or inlays. They may or may not be removable. They are made of common materials like rubber, leather, synthetic textiles that approximately take more than 50 years to fully decompose. Insoles can be used to provide cushioning, odor control, moisture management, protection, prevention of pain, and support to the feet [1]. Spacer fabric is a special kind of 3D fabric. The composition of weft knitted spacer fabric involves the interconnection or separation of two weft-knitted fabrics through the utilization of spacer yarns (Karahan et al., 2013). Various techniques such as knitting, weaving, nonwoven, and braiding can be employed to produce this sort of fabric. [2]. In each of these techniques, a minimum of three distinct yarns is employed for every layer. The spacing between the two layers of spacer fabric in weft knitting machines can be modified by adjusting the gap between the dial and the cylinder [3]. The spacer fabric with efficient and effective arrangement of fibers or yarns in the form of fabric, was considered instead of simple knitted fabric, because of its breathability, moisture management, compression, air permeability, and comfort properties [4]. The structure allows greater compressibility than woven fabrics and therefore exhibits better protection.

Material selection is important for comfort as well as selection of sustainable practices for the protection of resources [5]. It is our social responsibility to select sustainable materials. Cotton is a highly prevalent natural fiber that is extensively utilized on a worldwide basis. Cotton fibres are extensively used due to their breathability, strength, comfort, absorbency, and easy availability [6]. Cotton products are very popular among consumers due to their soft hands and comfortable wearing performance. Bamboo fiber is also a natural fiber and more sustainable than most textile fibers. The material is derived from the fibrous pulp of bamboo grass and its usage in different products is extensively growing. It shows better moisture management properties/wicking ability due to the presence of micro gaps and holes in fibrous structure. The fiber has an inherent smooth and rounded morphology, hence lacking any sharp protrusions that could potentially induce skin discomfort and no allergic reactions are reported like other natural fibers Wool or hemp. It has antibacterial properties that are retained after multiple washes, which results in odor resistant fabrics. Bamboo fabric exhibits insulating characteristics, so enabling it to regulate temperature well by promoting a cooler sensation during summer and a warmer experience in winter for the wearer [7-8]. Flax fiber is also one subject of intensive research in the field of materials science due to its environmentally friendly nature and good mechanical properties It is one of the oldest plant cultivated by mankind. Fabrics containing flax are renowned for their antibacterial attributes and often exhibit greater resistance to fungal proliferation in comparison to other natural fibers [9-13] Moisture regain for flax is 12%, Bamboo is 13%and that for cotton is 8.5% [7-10]. Polypropylene fibers were used in the tri–blend yarn due to its high strength, better thermal conductivity, and higher water vapor permeability. It is also easily available and cheap. Its moisture regain is 0.05% [14].

In their research, Hamedi et. al., investigated a technique aimed at enhancing the cushioning characteristics of a 3D weft knitted spacer fabric through the incorporation of NiTi monofilaments. They used polyester filament yarns to prepare the samples. There focused application for this fabric was to reduce the stress on human body due to impact especially on the diabetic foot by improving energy absorption of shoe insole 15]. Zhao et. al., studied the cushioning properties of spacer fabrics prepared on flat bed weft knitting machine. They used nylon/spandex yarns for outer layers and polyester monofilaments for middle layers. According to them, the spacer fabrics having smaller spacer yarn distance, coarse monofilament, an increase in the density of spacer yarns led to enhanced compression and energy absorption, while concurrently reducing resilience. This fabric was suggested to be useful to protect human body from daily life impacts [16]. X. Ye et al. developed warp knitted spacer fabrics for cushioning application using PES multi and mono-filament yarns. This fabric was useful alternative for PU foams, where comfort and recycling were concerned [17]. Rajan and Sundaresan studied the thermal properties of warp knitted based spacer fabric knitted from polyester multi and monofilaments. The samples were subjected to treatment using argon (Ar) and oxygen (O2) gases within a plasma reactor. They concluded that plasma treated spacer fabrics showed improved comfort properties in shoe insoles [18].

The objective of this work was to manufacture a shoe insole using spacer fabric made from natural fibers. The level of comfort experienced by individuals is determined by the interplay of heat and moisture transport qualities, as well as mechanical factors. Therefore, it is imperative to consider all of these characteristics during the design and manufacturing phases. The use of bamboo and flax in shoe insole would prove to be odour resistant due to anti-bacterial properties of these fibres already proved from literature. Moreover, the produced insole using double knit circular knitting machine and natural fibers, would be less costly beside better performance properties. The present study is structured around two primary aims. The initial aim is to the examination of the characteristics of the developed insoles. and second, is to compare their properties with market available sample by using Tukey's simultaneous analysis. The hypothesis was that they have similar properties by taking p equal to or greater than 0.05 (not significant).

2. Materials and Methods

2.1 Materials

This research was aimed at development of spacer fabric for shoe insole using natural fibers by weft knitting method. Spacer fabric is a type of textile that is knitted in three dimensions. It is created by interconnecting two layers of fabric using spacer yarn. To produce spacer fabric, three different yarns for each course is required. From the three types, one yarn for cylinder needle, second yarn for dial needle and a spacer yarn. Two types of insoles were prepared i.e., tri-blend insole and cotton insole. In one sample for both cylinder and dial, cotton yarn was used and nylon yarn as spacer yarn and in another sample for both cylinder and dial tri-blend yarn was used and nylon as spacer yarn. Blended yarn, of count 32/s, containing Bamboo, Flax, and polypropylene fibers was used to make tri-blend insole. The blend %age and the properties of these fibers are given in Table 1. The cotton yarn of 36/s was used to make cotton insole. Monofilament PA6 (Nylon) yarn, of 33 deniers, was used as a spacer yarn in both these insoles. Commercially available insoles which include leather insole, Bata black insole, and Bata Brown insoles etc. were also procured. For comparison with commercially available insoles, Bata Brown insoles were used.

Table 1

Blend percentage and Properties of Fibers used in Tri-Blend Yarn

Fibers	Blend (%)	Linear Density (denier)	Staple Length (mm)
Bamboo	85	0.133	38
Flax	10	1.5	32
Polypropylene	5	1.5	54

2.2 Methods

Samples were produced on 28 E gauge and 24’’diameter, double knit Interlock Circular Knitting Machine,1993 Terrot (Manufactured in Germany). Its creel capacity was 84 and it had 5952 needles and 42 feeders. The establishment of the gap between both fabric surfaces in weft knitting machines is achieved by modifying the dial height relative to the machine cylinder. The dial height was kept at 0.6 mm. The spacer fabric was knitted using dial and cylinder needles to create both the front and rear sides separately. Simultaneously, the interconnection of the fabrics through the monofilament nylon takes place by tuck stitches. Spacer fabrics are created by utilizing both high and low butt needles, which involves tucking on both the dial and cylinder needles at the same feeder, along with knitting on the dial needles. In feeders 1 and 3, the spacer yarn is knitted on the dial needle and tucked on the cylinder needles. The developed fabrics height/ space is 3.5+2 mm. The structure was shown in Fig. 1(a and b). which was developed on the SDS-ONE APEX platform design. Two insole samples were prepared i.e., Cotton insole and Tri-blend insole. The images of prepared samples are shown in Fig. 1(c). The shoe and the position of the insole in the shoe are shown in Fig. 1(d). The samples were subjected to typical atmospheric conditions for a duration of 24 hours in order to facilitate their relaxation.

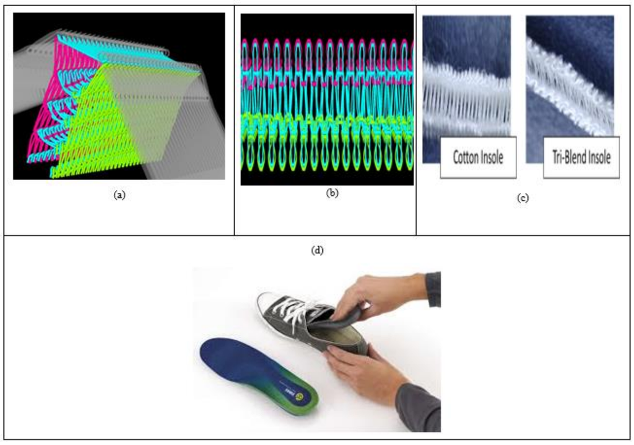

Fig. 1. (a) Structure Representation on Knitting on Machine (b) Loop Structure (c) Developed Cotton and Tri-Blend Spacer Fabrics, (d) Shoe and insole

The images of the developed show insole samples are shown in Fig. 2, where (a) represents the image of the Tri-Blend Insole Spacer Layer, (b) shows the Tri-Blend Spacer Fabric Insole Structure, furthermore, (c) shows the Cotton Insole Spacer Layer, and (d) depicts the Cotton Spacer Fabric Insole Structure.

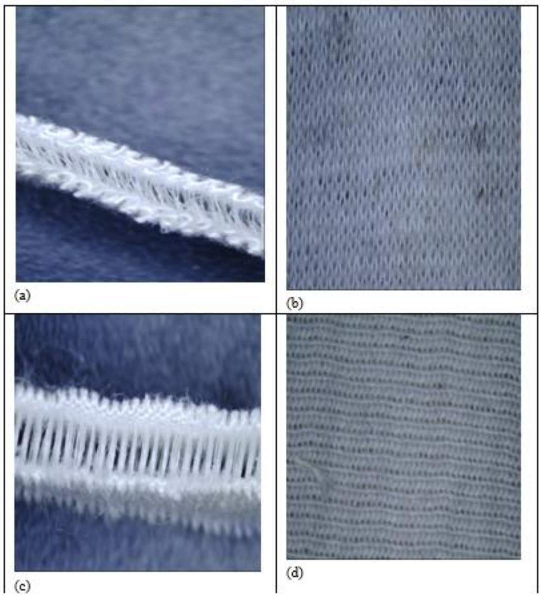

Fig. 2. Images of the Developed Shoe Insole Samples (a) Tri-Blend Insole Spacer Layer, (b) Tri-Blend Spacer Fabric Insole Structure, (c) Cotton Insole Spacer Layer, (d) Cotton Spacer Fabric Insole Structure

2.3 Testing

2.3.1 Puncture resistance of the insoles

Puncture resistance is the characteristic of the structure to resist the puncture caused by the sharp objects [19]. We need to develop puncture/stab resistant shoe soles to prevent foot from injury caused by material that can penetrate from outsoles of footwear. The Puncture Resistance of these samples was determined using Needle Penetration Tester according to EN-388. The speed of testing was set at 0.05 inch/min. The test was performed at 20.2°C temperature and 61.4% R.H.

2.3.2 Air permeability of the insoles

Air permeability (AP) is a vital bio-physical property of the textile material for applications in sportswear, footwear, and others. The term "air permeability" pertains to the ability of a fabric to allow the passage of gases and air. Air permeability makes the textile material thermally comfortable [20]. The AP of the samples was evaluated using the SDL Atlas Air Permeability (AP) Tester, following the guidelines provided in ISO 9237. Each sample was placed between the pressure clamps. The measurement area was set at 200 cm2 and pressure was set at 100 Pa. The test was carried out at 21°C temperature and 65% R.H. Its readings were obtained in mm/sec.

2.3.3 Moisture management property of the insoles

The moisture management property of the fabric is also referred to as breathability. This pertains to the fabric's ability to facilitate the transfer of moisture or perspiration from the body to the surrounding environment [21]. The humid climatic conditions of many Asian countries result in difficulty to dry the fabric. The act of wearing damp cloth while experiencing perspiration can result in pain for the individual donning the garment and increase the likelihood of infection. Therefore, this property is vital to make comfortable footwear and socks [22]. The Moisture Management Tester, in accordance with the AATCC-195 guidelines, was utilized to evaluate the fabric's OMMC. Samples of 8 x 8 cm were taken and a 0.9% solution containing 9 grams NaOH was made in 1 liter of distilled water. 0.22 cc of solution was allowed to drip on the paper and samples were placed between the sensors. The test was carried out at 21°C temperature and 65% R.H.

2.3.4 Thermal resistance of the insoles

Thermal resistance is another important property of the fabric structure which is related to comfort of the wearer. In the case of cushioning fabrics, the thermal resistance of the fabric causes discomfort as it is the property of the fabric to resist the flow of heat from body to the environment. The thermal resistance of these samples was determined according to ISO-11092 using Permetest. A sample of 80 mm diameter was mounted on the instrument. The test was carried out at 21°C temperature and 65% R.H.

2.3.5 Water vapour permeability of the insoles

The water vapour permeability of the fabric helps to maintain thermal equilibrium for the body by providing cooling through evaporation of sweat. This concerns the ability of the fabric to facilitate the transfer of vapors from the skin to the surrounding environment [23]. The water vapour permeability index of the insoles was tested according to BS-7209. The testing samples were first conditioned according to ISO-139 for 4 hours. The sample of 90 cm² was used for this test. Polyester monofilament woven mesh was used as a reference fabric having mesh aperture 18 µm, yarn diameter 32 µm, 196.1 threads per cm, and 12.5% open area. The test was carried out at 21°C temperature and 65% R.H.

2.3.6 Compression properties of the insoles

The insole material in contact with the foot must be soft in order to prevent any discomfort. Compression tests are performed to determine the softness and thickness of the samples by applying load on a 2 cm² area [24]. Compressibility may also be defined as decrease in thickness of fabric by increasing compressive force [24]. The compression properties of the insoles were tested according to KES-FB3. Load of 50N was used in this test. It gives four results.

Linearity of Compression (LC): It represents softness of the sample. The smaller the value of LC softer will be the fabric.

- Work of Compression (WC): It represents the amount of energy absorbed during pressure.
- Resilience of Compression (RC): It represents the recovery after compression. Higher value represents more recovery.
- Thickness at maximum load

2.3.7 Statistical analysis

Statistical analysis of the results was conducted using Minitab 18. A p-value below 0.05 signifies statistically significant factors at a 95% confidence level. The greater value of R-sq indicates greater effectiveness of the terms. Interval Plots and Tukey Simultaneous Plots were also studied for all these results. Interval plot shows the range of variations. Overlapping samples, in this plot, indicate insignificant difference between their means. The Tukey plot aids in establishing whether the variation between two samples is statistically significant or not. It indicates the insignificant difference between means of two samples, if their intervals contain zero in them.

3. Results and Discussion

To develop an environment friendly insole that could be employed as a commercial alternative insole for footwear industry, spacer fabric was produced and compared with commercially available insole. Heat

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and moisture transfer properties like AP, moisture management (MMT), thermal resistance, and water vapor permeability have a crucial effect over comfort properties. The mechanical contact that exists between the insole and the human body is also associated with tactile comfort, which encompasses compression qualities. Also puncture resistance, which is related to durability determines the resistance against sharp objects and is related to footwear products. Collectively heat and moisture transfer properties with mechanical properties influence the situation of wearer's comfort. The results obtained from above mentioned tests are given in Table 2.

Table 2

Testing Results of Cotton, Tri-Blend, and Commercial Insoles

		Cotton Insole	Tri-Blend Insole	Commercial Insole
Puncture Resistance (N)		42.54	61.42	53.19
Air Permeability (mm/sec)		507.6	284	56.53
Overall Moisture Management Capability (OMMC)		0.08	0.36	0
Thermal Resistance (m^2K/W)		0.021	0.023	0.069
Water Vapor Permeability Index		87.57	90.71	6.5
Fabric Compression Properties	Linearity of Compression (LC)	0.4004	0.45	0.84
	Work of Compression ($gf.cm/cm^2$)	0.96	1.13	0.36
	Resilience of Compression (%)	48.39	49.2	61.62
	Thickness at Maximum Load (mm)	2.29	2.5	5.25

3.1 Puncture Resistance of the Insoles

The puncture resistances of the cotton, tri-blend, and commercial insoles are 42.54 N, 61.42 N, and 53.19 N, respectively. The Bata insole is a triple layer bonding of fabric, foam, and rubber. The spacer fabrics show greater puncture resistance due to easy slippage and stretchability of yarns [25]. Tri-blend insoles show greater puncture resistance than cotton due to the presence of bamboo and flax in it. Both, bamboo, and flax yarns show better strength and elongation properties as compared to cotton [10, 26]. According to Table 3, a p-value below 0.05 signifies a statistically significant impact of the material type on the puncture resistance of the samples with 98.73% R-sq value. Fig. 3(a) and Fig. 3(b) show the Interval plot and Tukey Simultaneous plot for the puncture resistance of the samples, respectively. The interval plot of puncture resistance lacks overlapping intervals of the samples indicating statistically significant difference between means of the samples. Similarly, the Tukey simultaneous plot shows that none of the pair has zero in their ranges. Hence, the difference of means for puncture resistance of all the samples is significant.

Table 3

Analysis of Variance and Model Summary for Puncture Resistance of the Samples

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	2	716.813	358.407	350.63	0.000
Error	9	9.200	1.022		
Total	11	726.013			

S	R-sq	R-sq(adj)	R-sq(pred)
1.01103	98.73%	98.45%	97.75%

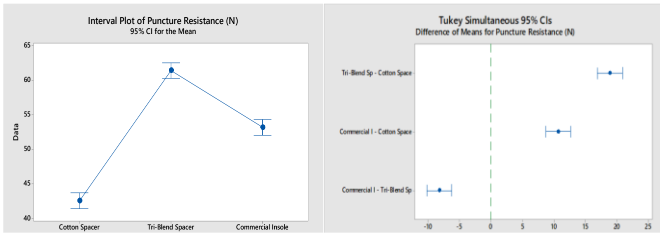

Fig. 3. (a) Interval and (b) Tukey Simultaneous Plots for Puncture Resistance Of The Samples

3.2 Air Permeability of the Insoles

The air permeability of the cotton, tri-blend, and commercial insole is 507.6 mm/sec, 284 mm/sec, and 56.53 mm/sec respectively for face side and 501.6 mm/sec, 279 mm/sec, and 36.82 mm/sec respectively for back side. The air permeability of cotton insoles is highest and that for commercial insoles is lowest. The air permeability of commercial insoles is lowest due to close surface structure resulting in lower passage for air as compared to spacer fabrics 20]. The air permeability of cotton insoles is greater than that of the tri-blend insoles due to smaller thickness. Thickness has an inverse relation with air permeability of the fabrics. From Table 4, the p-value less than 0.05 indicates statistically significant effect of composition on the air permeability of the samples with 100.00% R-sq value. Fig. 4(a) and Fig. 4(b) show the Interval plot and Tukey Simultaneous plot for the air permeability of the samples, respectively. The interval plot of air permeability does not show overlapping intervals of the samples indicating statistically significant difference between means of the samples. Similarly, it can be seen in Tukey simultaneous plot that none of the pair has zero in their ranges. Hence, the difference of means for air permeability of all the samples is significant.

Table 4

Analysis of Variance and Model Summary for Air Permeability of the Samples

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	2	406938	203469	180768.62	0.000
Error	9	10	1		
Total	11	406948			

S	R-sq	R-sq(adj)	R-sq(pred)
1.06093	100.00%	100.00%	100.00%

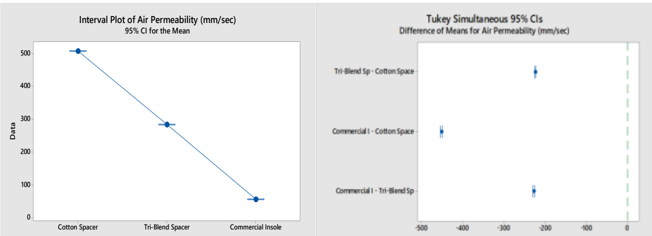

Fig. 4. (a) Interval and (b) Tukey Simultaneous Plots for Air Permeability of The Samples

3.3 Liquid Moisture Management Property of the Insoles

The OMMC of the cotton, tri-blend, and commercial insole is 0.08, 0.36, and 0 respectively. The OMMC for commercial insoles is zero due to the compactness of the structure. It lacks pores required for the passage of moisture. The OMMC of tri-blend insole is greater than that of the cotton insole due to the presence of bamboo fibers in it. The bamboo fibre contains micro gaps and pores resulting in better moisture management than cotton [7]. From Table 5, the 0.000 p-value indicates statistically significant effect of material composition on the OMMC of the samples having 99.71% R-sq value. Fig. 5(a) and Fig. 5(b) show the Interval plot and Tukey Simultaneous plot for the OMMC of the samples, respectively. The absence of overlapping intervals in the interval plot of OMMC represents statistically significant difference between means of the samples. Similarly, in Tukey simultaneous plot, none of the pair contain zero in their ranges. Therefore, the difference of means for OMMC of all the samples is significant.

Table 5

Analysis of Variance and Model Summary for OMMC of the Samples

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	2	0.285867	0.142933	1546.15	0.000
Error	9	0.000832	0.000092		
Total	11	0.286699			

S	R-sq	R-sq(adj)	R-sq(pred)
0.0096148	99.71%	99.65%	99.48%

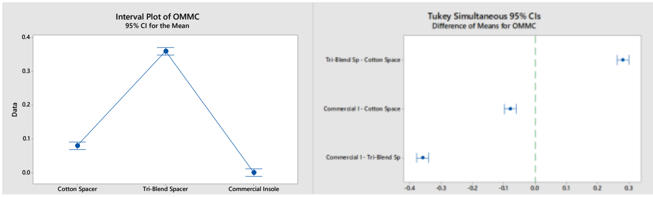

Fig. 5. (a) Interval and (b) Tukey Simultaneous Plots for OMMC of The Samples

3.4 Thermal Resistance of the Insoles

The thermal resistance for cotton, tri-blend, and commercial insole is 0.021 m^2K/W, 0.023 m^2K/W, and 0.069 m^2K/W respectively. The presence of air in the material structure resists the flow of heat and hence increases its air resistance [27]. The foam contains air bubbles in it resulting in higher thermal resistance [28]. That's why the thermal resistance of commercial insole is greater than the spacer fabrics. From the results, negligible effect of fiber composition could be seen on the thermal resistance of spacer fabrics. From Table 6, the p-value less than 0.05 indicates statistically significant effect of material on the thermal resistance of the samples having 91.30% R-sq value. Fig. 6(a) and Fig. 6(b) show the Interval plot and Tukey Simultaneous plot for the thermal resistance of the samples, respectively. The interval plot of thermal resistance shows overlapping intervals of the spacer samples indicating statistically non-significant difference between means of both spacer fabrics. Tukey simultaneous plot shows zero in the ranges of cotton and tri-blend spacer fabrics. Remaining two pairs do not have zero in their ranges. Therefore, the difference of means in the thermal resistance of spacer fabrics and rubber sole is significant while the difference for both spacer fabrics is not significant.

Table 6

Analysis of Variance and Model Summary for Thermal Resistance of the Samples

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	2	0.005899	0.002949	47.23	0.000
Error	9	0.000562	0.000062		
Total	11	0.006461			

S	R-sq	R-sq(adj)	R-sq(pred)
0.0079022	91.30%	89.37%	84.54%

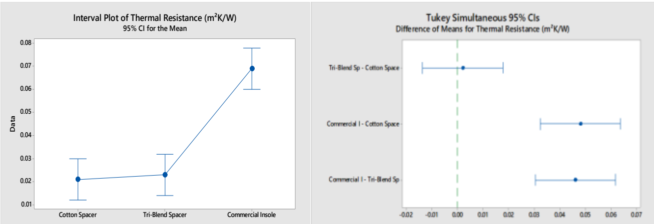

Fig. 6. (a) Interval and (b) Tukey Simultaneous Plots for Thermal Resistance of The Samples

3.5. Water Vapour Permeability of the Insoles

The water vapour permeability index for cotton, tri-blend, and commercial insoles is 87.57, 90.71, and 6.5 respectively. The water vapour permeability of the commercial insole is lower than spacer insoles due to the compact structure and absence of pores required for water vapour transportation [20]. Negligible effect of fibre composition was observed on the water vapour permeability of spacer fabrics. From Table 7, the p-value less than 0.05 indicates statistically significant effect of material composition on the water vapour permeability of the samples having 99.95% R-sq value. Fig. 7(a) and Fig. 7(b) show the Interval plot and Tukey Simultaneous plot for the water vapour permeability index of the samples, respectively. The interval plot represents statistically significant difference between means of the samples as none of the intervals are overlapping. Similarly, in Tukey simultaneous plot, none of the pair contain zero in their ranges. Hence, the differences in the means of water vapour permeability index of all the samples are significant.

Table 7

Analysis of Variance and Model Summary for Water Vapor Permeability of the Samples

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	2	18231.4	9115.69	9923.70	0.000
Error	9	8.3	0.92		
Total	11	18239.6			

S	R-sq	R-sq(adj)	R-sq(pred)
0.958425	99.95%	99.94%	99.92%

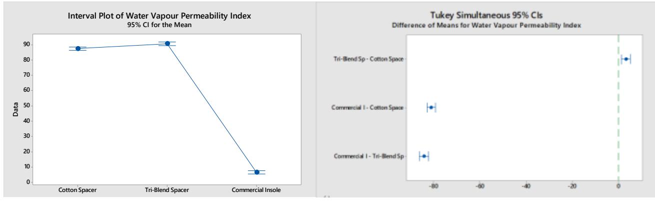

Fig. 7. (a) Interval and (b) Tukey Simultaneous Plots for Water Vapor Permeability of The Samples

3.6 Compression Properties of the Insoles

The linearity of compression for cotton, tri-blend, and commercial insole is 0.4004, 0.45, and 0.84 respectively. Smaller value of LC represents greater softness. Negligible difference is seen in the LC of cotton and tri-blend insoles. The softness of spacer insoles is greater than that of commercial foam insoles. This is because the density of the spacer fabrics is smaller than that of the commercial insole (foam and rubber) due to the presence of spacer layer. The spacer yarns in the spacer layer bundle up increasing the compressibility of the fabric. The denser structure of the commercial insole reduces its compressibility. From Table 8, the p-value less than 0.05 indicates statistically significant effect of material on the LC of spacer fabric with 91.39% R-sq value. Fig. 8(a) and Fig. 8(b) show the Interval plot and Tukey Simultaneous plot for the LC of the samples, respectively. The interval plot of LC shows overlapping intervals of the spacer samples. Hence, there is statistically non-significant difference between means of both spacer fabrics. Tukey simultaneous plot has zero in the ranges of cotton and tri-blend spacer fabrics. The remaining two pairs do not have zero in their ranges. Therefore, the difference of means in the LC of spacer fabrics and rubber sole is significant while the difference in the means of LC for both spacer fabrics is not significant.

Table 8

Analysis of Variance and Model Summary for Compression Properties

	P-Value	R-square
Linearity of Compression	0.000	91.39%
Work of Compression (gf.cm/cm^2)	0.000	94.19%
Resilience of Compression (%)	0.000	98.85%
Thickness at Maximum Load (mm)	0.000	99.41%

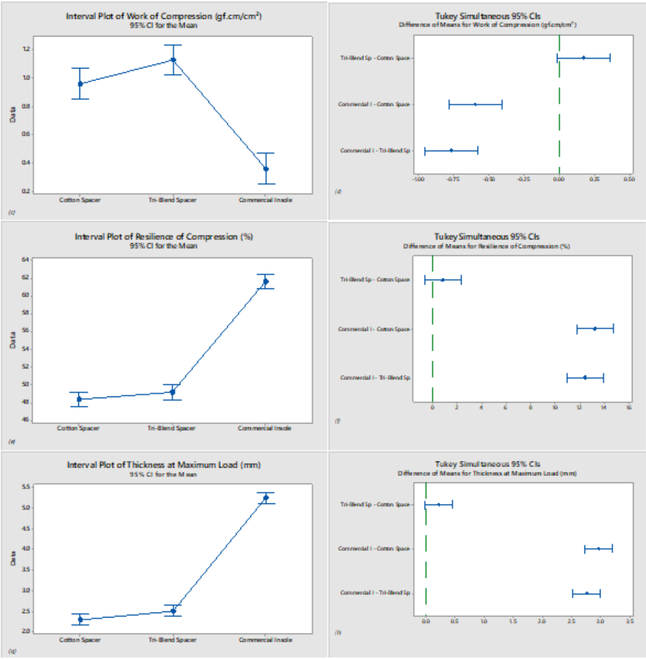

Fig. 8. Interval and Tukey Simultaneous Plots for Compression Properties

The work of compression for cotton, tri-blend, and commercial insoles is 0.96 gf.cm/cm², 1.13 gf.cm/cm², and 0.36 gf.cm/cm² respectively. The WC for the spacer insoles is greater than foam insoles due to the slippage and stretch ability of yarns. The commercial insole, made from foam, has an open cell structure. Foams with open cell structures show weaker energy absorption system due to presence of air bubbles [28]. The three-layers of spacer fabrics can easily absorb the pressure force through the spacer structure, hence increasing the work of compression [29-31]. Monofilaments act as linear springs when the fabric is compressed from Table 8, the p-value less than 0.05 indicates statistically significant effect of material type on the WC of the samples having 94.19% R-sq value. Fig. 8(c) and Fig. 8(d) show the Interval plot and Tukey Simultaneous plot for the WC of the samples, respectively. The interval plot of WC has the overlapping intervals of the spacer samples indicating statistically non-significant difference between the means of both spacer fabrics. Tukey simultaneous plot shows zero in the ranges of cotton and tri-blend spacer fabrics. Remaining two pairs lack zero in their ranges. Therefore, the difference of means in the WC of spacer fabrics and rubber sole is significant while the difference in the means of WC for both spacer fabrics is not significant.

The resilience of compression for cotton, tri-blend, and commercial insoles is 48.39%, 49.2%, and 61.62% respectively. It can be observed that fibre type had no effect of resilience of the spacer fabrics. Negligible difference was seen in the RC of spacer fabrics. The RC of commercial foam insoles is greater than that of the spacer insoles. Structures with lower compressibility resist the deformation and show more resilience. From Table 8, the p-value less than 0.05 indicates statistically significant effect of material on the RC of insoles with 98.85% R-sq value. Fig. 8(e) and Fig. 8(f) show the Interval plot and Tukey Simultaneous plot for the RC of the samples, respectively. The interval plot of RC shows overlapping intervals of the spacer samples indicating statistically non-significant difference between means of both spacer fabrics. The Tukey simultaneous plot shows zero in the ranges of cotton and tri-blend spacer fabrics. The remaining two pairs do not have zero in their ranges. Therefore, the difference of means in the RC of spacer fabrics and rubber sole is significant while the difference in means for RC of both spacer fabrics is not significant.

The thickness of the cotton, tri-blend, and commercial insoles at 50 N is 2.29 mm, 2.5 mm, and 5.25 mm respectively. The thickness of commercial insole is greater than that of the spacer insoles as it contains foam and rubber. The collective density of foam and rubber is greater than that of the spacer layer in spacer fabrics. The lower compressibility of the commercial insole shows smaller deformation. Hence, the thickness of commercial insole at maximum load is greater than the spacer fabric. Negligible effect of fibre type was observed in thickness of spacer fabrics resulting in similar thickness values for both spacer fabrics. From Table 8 the p-value less than 0.05 indicates statistically significant effect of material type on the thickness of the samples at max load having 99.41% R-sq value. Fig. 8(e) and Fig. 8(f) show the Interval plot and Tukey Simultaneous plot for the thickness of the samples at maximum load. The interval plot for the thickness of the samples at maximum load shows overlapping intervals of the spacer samples, respectively. Hence, there is statistically non-significant difference between the means of both spacer fabrics. Tukey simultaneous plot has zero in the ranges of cotton and tri-blend spacer fabrics. The remaining two pairs do not have zero in their ranges. Hence, the difference of means in the thickness of spacer fabrics and rubber sole, at maximum load, is significant while the difference in means for thickness of both spacer fabrics, at maximum load, is not significant.

4. Conclusion

The purpose of this work was to produce a shoe insole by weft knitting technique using natural fibres with better comfort properties. From testing results and statistical analysis, it can be concluded that the weft knitted spacer fabrics made from cotton or tri-blend yarns are better than commercially available insoles in all aspects i.e. they have better mechanical and comfort properties. İt was also noticed that type of insole i.e. spacer fabric or rubber sole, had a statistically significant effect on all the properties. Statistically non-significant effect of yarn type was observed on the compression properties and thermal resistance in case of spacer insoles. The spacer fabrics made from tri-blend yarn would be beneficial as a shoe insole as it has better properties than commercial insole and anti-bacterial fibers are used in it. İt will be beneficial in manufacturing of odor resistant shoe insole. The findings of this study have the potential to serve as a foundation for future advancements in footwear design through the incorporation of natural fibres. The objective of this research was to design and fabricate a spacer insole that may serve as a viable substitute for traditional leather or rubber materials in the footwear sector, with the aim of augmenting certain characteristics. The implementation of this material and production technique is expected to contribute to the mitigation of adverse environmental consequences. The process of material selection plays a pivotal role in the development of environment friendly footwear.

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