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Evaluation of Comfort Characteristics of Milk Protein Fabric for Apparel End-use

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ABSTRACT

Casein is natural and well known for its soft and delicate nature due to the presence of higher protein content. In this research, casein fabric was developed and evaluated for air permeability, moisture management ability, and different low-stress mechanical properties including tensile, shear, bending, the coefficient of friction, surface roughness, values of linearity, compression work, and resilience. The developed casein fabrics were also evaluated subjectively to analyze comfort parameters. The results showed that the knitted casein fabric exhibited higher air permeability than cotton fabric and shares the same rating with cotton overall moisture management capacity index (OMMC) level. The casein fabric has higher extensibility under low stress along with lower toughness. The bending rigidity and hysteresis (at both the angles) values of casein fabric are also lower than cotton. Additionally, the casein fabric displayed better drape-ability than cotton fabric. The compression and surface friction values observed are slightly higher than cotton fabric. In the subjective analysis, out of 20 subjects, 18 reported the fabric as best compared to cotton fabric in terms of overall comfort aspects.

Keywords: Milk protein fabric, Overall management capacity index (OMMC), Mechanical Properties, Objective measurement, Subjective measurement

Introduction:

Milk fiber is a new generation fiber and a kind of synthetic fiber made of milk protein (casein) through bioengineering method with biological health care function and natural & long-lasting antibacterial effect [1]. The manufacturers of milk fiber claims that these fibers are most comfortable, possesses excellent water transportation and air permeability [2]. The casein has a pH value similar to that of human skin and biodegrades as well. The first experimentation was done during the early 1930s. An Italian scientific expert Antonio Ferretti explored different avenues regarding casein filaments and he was effective, making casein filaments that were malleable and had numerous properties connected with wool and cotton which was required by individuals on the bleeding edges. These fiber materials were utilized as a part of numerous dress and household items in America and Europe amid the 1930s [3]. In 1936 the yield of Lanital, the first commercial regenerated protein fiber, was about 300 tons by the next year it had come to 1200 tons and in 1939 the creation limit was 10000 tons a year [4]. However, it fell out of use after WWII ended and newer, cheaper synthetics such as nylon grew in popularity [3]. Manufacturing environment-friendly products in a sustainable way are the most important and emerging issue in the present scenario. The main focus comprises not only on the quality of the products but also it focuses on the sustainability in manufacturing processes including raw material resources from cradle to grave. In recent times a lot of natural resource-based textile fibers were on the market. In this regard, the casein fibers are back in trend due to their potentiality [5-14]. The milk protein contains the natural humectants factor, which can capture moisture and this will maintain the skin's moisture [1]. However, the research on casein fiber was found to meager compared to other fiber material, only a few researchers like Diamond and Wormell [15], Whittaker and Heim [16], and Wormell [17] did in the early years. They had analyzed the fiber properties like tensile strength, elongation, etc., but there are no previous studies found in the literature, regarding the fabric handle values for clothing purposes.

Intimate apparel is depicted as a human's second skin, so is the most important clothing layer for achieving comfort [18]. This is the fundamental reason behind the mass usage of cotton fiber in the intimate apparel manufacturing industry. In a survey conducted by the leading research organization, two-thirds of consumers mentioned that it was important for them that their underwear is made of cotton [19]. About half of consumers in the survey mentioned that they were concerned about the increase in manmade fibers in their intimate apparel. The report also mentioned that the consumers are seeing that the change as a change in their fundamental quality, comfort, and versatility requirements [19]. This is mainly due to their previous experiences of respondents with the cotton-based intimate apparel. The intimate apparels act as a medium to transport the perspiration and body heat from the skin. As the comfort property of the clothing material mainly depends upon the thickness of the fabric, tightness of fabric construction, and hygroscopic in type, the improved softness of casein fiber may provide better comfort as intimate apparel [20]. Hence, this study attempts to evaluate the air, moisture management, and mechanical properties of the casein knitted fabric using objective and subjective evaluation methods and to analyze the potential applications of casein fabric for intimate apparel end-use.

Materials and Methods:

Souring of yarn

For this study, 100% casein ring-spun yarn was sourced from Euroflex Industries Pvt Ltd, Mumbai, India. The count of the purchased yarns was 40's. The yarns were knitted with an interlock structure with 170 grams per square meter. A cotton fabric with similar grams per square meter and yarn count was purchased from a retail outlet. Both fabrics were scoured, bleached, and fully relaxed before the testing process as per the procedure mentioned by Karmakar (1999) [21]. The details of the selected fabrics were provided in Table 1.

Table 1. Details of the selected fabric

S.No	Fabric	CPI	WPI	GSM	Thickness in mm	Loop Length in mm	Yarn count in Tex	Fiber density (g/cu.mm)
1.	100% Cotton fabric	54	48	174	0.86	3.034	14.7625	0.00154
2.	100% Casein fabric	48	36	170	0.74	3.257	14.7625	0.0013

Fabric parameter analysis

The tightness factor values and the porosity value of the selected cotton and casein fabrics were calculated using the following formula,

i. Tightness factor $= \frac{\sqrt{\text{Tex}}}{\text{Loop length}}$ ----- 1 [22]

ii. Tightness factor $= \frac{\text{Yarn diameter}}{\text{Loop length}}$ --- 2

Where yarn diameter,

d (in inches) = $\frac{1}{(29.3\sqrt{\text{Yarn packing fraction x fiber density x yarn count}}}$, as reported by Seyam [23]

iii. Porosity % = $[\, 1 - (\frac{\text{W x L X} \sqrt{\text{Tex}}}{\rho \text{ x } 88 \text{ x } 10^3})]$ x 100% ----- 3

Where

C= Courses/mm, W =Wales/mm, L = loop length in mm, ρ = fiber density in gm/mm3 [24].

FTIR analysis

FT-IR spectra for the casein knitted fabric were measured with a SHIMADZU spectrophotometer to identify the presence of functional substance related to casein protein in the fabric. The spectra were obtained in the range of 400 to 4000 cm^{-1}.

Air and Moisture-management properties

The air permeability of the cotton and casein fabrics was performed as per BS 3424-16:1995, Method 18, determination of air permeability. The moisture management ability of the fabric samples was tested on SDL ATLAS M290 - moisture management tester (MMT) in terms of one-way moisture transport capability percentage, and overall moisture management capacity index (OMMC) according to AATCC test method 195–2009.

Objective evaluation of low-stress properties

The developed casein fabric was completely relaxed and tested on Kawabata KES-FB1-5 tester for different fabric mechanical properties such as tensile, shear, and bending (the force required to bend the fabric at 0.1-1 cm curvature). The coefficient of friction (MIU) and surface roughness (SMD) was obtained through the different probes. Again compression tests were also measured through another probe. Tests were designed to provide values of linearity (LC), compression work (WC), and resilience (RC). These tests also provide the data for the degree of compression, deformation, and recovery of the test fabric at 0-50 gf/cm^2 [25].

Wear trial analysis of comfort properties

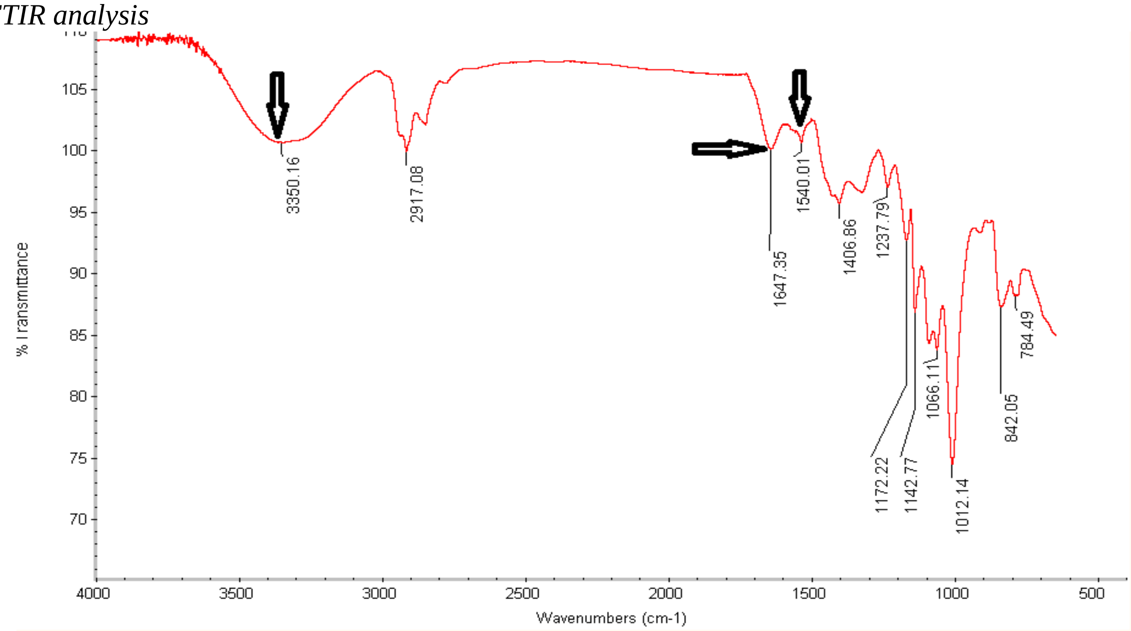
The knitted casein fabric was constructed as a slip, a girl's intimate apparel. The developed samples were laundered and given to volunteers for a one-week wear trial. In wear trial analysis, 20 volunteers were selected from undergraduate students and their age group ranges from 21-23. The volunteers were asked to use the garment daily during work hours, approximately eight hours per day. Daily after use, they were asked to launder the garment and use it for the next day. At the end of the week after 5 days, the volunteers' feedback was obtained in the form of a rating. After the trial, the volunteers were asked to rate the performance of the garment from 1 – 5, where 1 is low, and 5 is excellent, by comparing it with their regular garment in terms of the factors like Softness, Stiffness, Lightness, snugness, smoothness, absorbance, warmth, Prickle, Stickiness, Clinginess, Scratchiness, Dampness and overall comfort [26]. The sample garment is provided in Figure 1. The 20 samples were produced in standard sizes like small, medium, and large size measurements.

a) b)

Figure 1. Image of developed slip using casein fabric (Size: medium)

Results and Discussion:

FTIR analysis



a)

b)

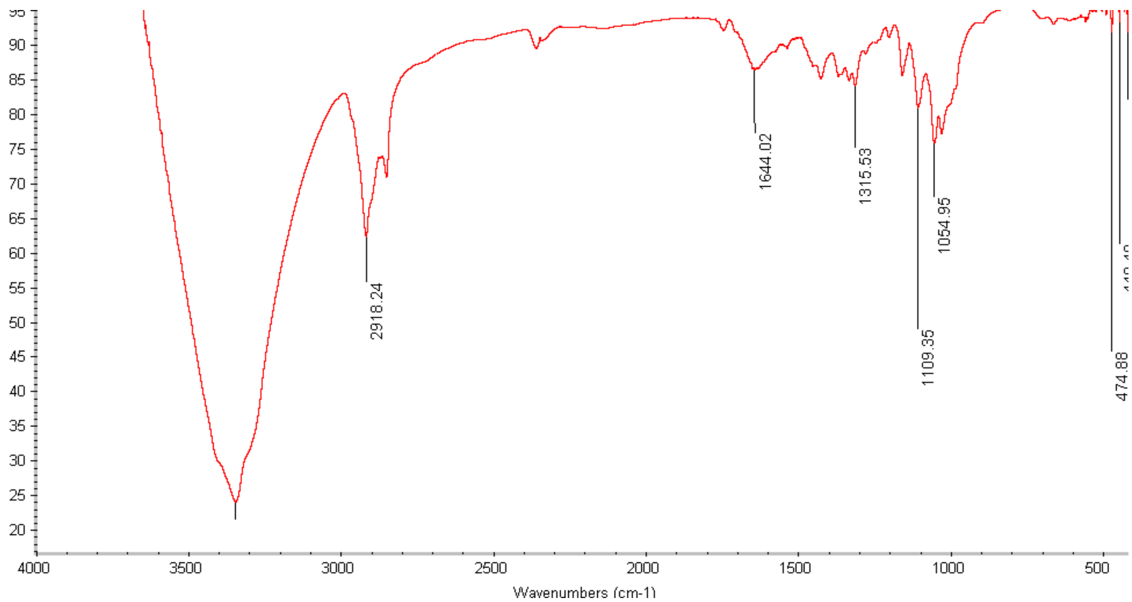


Figure 2. FTIR spectrum of a) Casein fabric, b) Cotton fabric

The sourced yarns were characterized to identify the chemical groups of casein components. The results were given in Figure 2 a). From figure 2, it can be seen that the absorption peak is 1647 cm^{-1} represents c = o structure, amide I bond which is the protein conformation [27]. Peak 1540 cm^{-1} represents a strong amide II bond that forms due to N-H bonding of C-N -H group [28]. The peak 3350 cm^{-1} represents strong absorption due to N-H structure. These absorption peaks are the essential and identification spectrum of casein fiber. This confirms that the fiber material used in this structure was casein [29].

The FTIR spectra of the cotton fabric are provided in Figure 2 b). The absorbency peaks at 3350 cm^{-1} represent the O-H Stretch, the peak at 2918.24 cm^{-1} denotes the C-H (1) asymmetric stretch, the peak at ~1700 cm^{-1} and 1644.02 cm^{-1} represent the C=O stretch of a carboxylic acid & ester. These peaks were the common vibrational modes and mode assignments corresponding to components of cotton fiber [30-31].

Air and Moisture management analysis

The moisture management ability of the casein and cotton fabric was analyzed using a moisture management tester. The average results of three test runs were presented in Table 2. The time taken for wetting the surface of the fabric is noted. For casein fabric, it is observed as 3.46 seconds on the top surface and 3.65 seconds on the bottom surface. The cotton showed better value concerning the wetting time with 2.15 seconds at the top surface and 1.19 seconds at the bottom surface. Out of the selected fabric, the faster wetting ability was noted with cotton fabric.

Table 2. Air and Moisture management test results of casein and cotton fabric

Fiber	Wetting time(sec)	Absorption rate(%/sec)	Max Wetted radius(mm)	Spreading speed(mm/sec)	One way transport capability(%)	OMMC	Air permeability (cm^3 /cm^2/sec)
Casein Top Surface	3.469	66.27	25	5.016	252.51	0.7546	155
Casein bottom Surface	3.656	70.64	25	5.033			
Cotton Top surfaces	2.156	50.04	20	3.792	285.82	0.7168	59.5
Cotton Bottom Surface	1.969	43.66	25	4.301			

The absorption rate is an average speed of liquid moisture absorption for the top and bottom surfaces of the specimen during the initial change of water content during a test. The casein fabric has an absorption rate of 66.27%/s on the top surface and 70.64 %/s on the bottom surface which is higher than cotton (50.046 %/s on the top and 43.6618 %/s at the bottom). The result shows that the maximum wetting radiuses of casein and cotton fabric are found to be similar. For casein, fabrics are 25 mm on the top and 25 mm at the bottom and for the cotton fabrics, the top wetting radius is 20 mm and the bottom wetting radius is also 25 mm. This difference between casein and cotton fabrics happens when the structure allows more dispersion of liquid.

Accumulated rate of surface wetting from the center of the specimen, where the test solution is dropped to the maximum wetted radius. The spreading rate of casein is 5.0169 mm/s on the top and 5.0335 m/s on the bottom surface. Cotton has 3.7921 mm/s on the top and 4.3019 mm/s at the bottom. One way transport capacity is the difference in the cumulative moisture content between the two surfaces of the fabric in the unit testing time. Negative values mean that the cumulative moisture content on the back surface of the fabric is higher than on the face surface [32]. The value for casein is 252.51% and cotton is 285.82%. The performance of both the fabric was noted very similarly in the One-way transport capacity of the moisture.

The fabric's ability to manage and transport the liquid moisture was evaluated through the parameter, overall moisture management capacity (OMMC). The value of OMMC is mainly influenced by the spreading speed of the liquid on the fabric surface. The other variables like drying speed, moisture absorption rate of the bottom side, and one–way liquid transportability also has its role in the OMMC calculations [32, 33]. Higher overall moisture management capacity indicates better overall moisture transportability of the fabric. The OMMC grading of casein fabrics is slightly higher than that of cotton fabrics. The grading table (as per AATCC 195–2009) indicates that the OMMC value from 0.6-0.8 comes under the class of "Very good". Here for casein fabric, the value noted is 0.75 and for cotton, it is 0.7. The results of the air permeability test show that the casein fabrics have a higher air permeability of 155m^3 /cm^2 /s, than cotton fabric (59.5cm^3 /cm^2 /s). The air permeability results were an average of five readings. From the results, it can be understood that the casein also has comparable moisture management properties with cotton fabric, and in some specific parameters like spreading area and absorption rate; the casein fabric performs better than cotton. In the case of air permeability, casein fabric performance was noted better than cotton due to the slightly higher porosity (Figure 3) of the casein fabric than the cotton fabric. The detailed calculation of the fabric porosity and tightness values of the selected fabrics are provided in Table 3. The results can also be correlated with the higher hairiness of the cotton fabric as provided in Figure 3.

Table 3. Porosity and tightness factor calculation of the casein and cotton knitted fabric

Fabric type	Courses /mm	Wales/ mm	Loop Length in mm	Yarn count in Tex	Fiber density (g/cu.mm)	Tightness factor as per Eq 1	Tightness factor as per Eq 2	Porosity %
100% Cotton fabric	2.13	1.89	3.034	14.7625	0.00154	1.266	0.0476	94.31
100% Casein fabric	1.89	1.42	3.257	14.7625	0.0013	1.179	0.0499	95.14

a) 

b) 

Figure 3. Microscopic image of the a) casein and b) cotton knitted fabric

Low-stress mechanical properties evaluation

Table 4. Low-stress mechanical properties of knitted casein and cotton fabric

KES Parameter	Course	Wales	Avg
LT - Casein	0.739	1.061	0.900
Cotton	0.689	1.231	0.960
WT (gf.cm/cm$^{2)}$ - Casein	0.42	0.28	0.32
Cotton	0.58	0.34	0.46
RT (%)- Casein	44.71	32.76	38.73
Cotton	45.12	33.01	39.06
EMT (%)- Casein	2.24	1.605	1.84
Cotton	2.01	1.621	1.81
G (gf/cm.deg) - Casein	0.74	0.74	0.74
Cotton	0.82	0.84	0.83
2HG (gf/cm) - Casein	2.11	3.15	2.63
Cotton	2.15	3.14	2.64
2HG5 (gf/cm) - Casein	2.22	3.10	2.66
Cotton	2.31	3.25	2.78
B (gf.cm^2/cm) - Casein	0.0443	0.0087	0.0265
Cotton	0.0521	0.0086	0.0303
2HB (gf.cm/cm) - Casein	0.0423	0.0081	0.0252
Cotton	0.0431	0.0085	0.0258
MIU - Casein	0.169	0.210	0.190
Cotton	0.121	0.189	0.155
MMD - Casein	0.0088	0.0327	0.0207
Cotton	0.0056	0.0241	0.014
SMD (µm) - Casein	2.71	9.88	6.29
Cotton	2.89	10.12	6.50
		Fabric Properties	
LC - Casein		0.771	
Cotton		0.656	
WC (g.cm/cm^2) - Casein		0.055	
Cotton		0.042	
RC (%)- Casein		78.12	
Cotton		77.60	
Fabric Thickness (T_0) (mm) - Casein		0.706	
Cotton		0.698	
Fabric Thickness at max. pressure(T_m) (in mm) - Casein		0.576	
Cotton		0.582	

Tensile properties

The tensile property values such as EMT, LT, WT, and RT values are given in Table 4. EM gives the tensile strain under strip biaxial extension. Extensibility has a good correlation with fabric handle. The higher the extensibility, the better is the fabric quality from the point of view of the handle. The wearing comfort of the fabric increases with the increase in the EM value. Here from the results, it was noted that the casein fabric had a value of 1.84% and cotton possess 1.81%. The results implicate that both cotton and casein fabric has similar extensibility with 500 N/m strain. In the case of casein fabrics, the average LT value was 0.9 and cotton has 0.96. The stress and strain curve is a straight line when LT = 1. Hence, the casein fabrics have a higher amount of linear extension with the load. The linearity of tensile property (LT) is indicative of wearing comfort. When LT is small, fabric extensibility in the initial strain range will be high, and this gives comfort in wearing the cloth. A higher value of LT means the more elastic recovery of fabric at a particular load. The higher LT values are always better in terms of the dimensional stability of the fabric [34].

WT value of casein fabric was 0.32 from Table 4. In general, the WT value is indicative of fabric toughness. The WT value represents the garment's ability to deform. The higher toughness represents the poor /lower hand value [35]. The casein fabric result gives the lowest toughness value due to the inherent low modulus of them, which would probably help in improving the fabric handle. These findings can also be supported by the lower tightness factor values of the casein fabric (as per equation 1). However, when the yarn packing factor is considered (as per equation 2) there is no much difference noted between the structures. The WT value of the cotton fabric noted as 0.46, showing that cotton fabric will result in comparatively high toughness than casein fabric. The resilience value (RT) of the casein and cotton fabric was noted as 38.73 and 39.06. Tensile Resilience property is indicative of fabric recovery after tensile deformation. The higher the tensile resilience of a fabric, the better is its fabric handle. The 38% of resilience shows that the handle property of the fabric was in a medium category. The tensile resilience property of the casein fiber is mainly correlated with the percentage of amorphous and crystalline regions in the fiber. Since the casein yarn was directly sourced from the manufacturers, the morphological data obtained are not analyzed. However, the performance of the casein fabric is slightly lower than the cotton fabric in the case of RT. The modulus and tensile resilience values of the knitted fabric at low strain are mainly attributed to the structural parameters and only at high strain, the material will experience the stretch. However, the higher toughness and lower resilience values of cotton fabric are due to the higher inter-fiber friction of cotton fabric than casein fabric. This is very evident from the higher compact structure, lower porosity, and higher thickness of the cotton fabric.

Shear properties

From the test result reported in Table 2, the shear rigidity (G) value of the casein fabric was noted as 0.74 and for cotton fabric, it is 0.83. The shear rigidity of fabric depends on the mobility of cross threads at the intersection point, which again depends on the structure, yarn diameter, and the surface characteristics of both and yarn [36]. The lower value of the shear rigidity provides better fabric handle properties. A high value of G indicates a paper-like property and causes difficulty in tailoring and discomfort in wearing. The coefficient of friction is another factor that has a direct influence on the shear rigidity of the fabric. If the coefficient of friction is high, it prevents the movement of yarn in the body of the fabric during the application of shear force and particularly when deformation is taking place at low-stress levels [37].

For the Hysteresis of Shear value, the 2HG and 2HG5 values represent the hysteresis of shear force at 0.15 degree and 5 degrees, the values noted for casein fabrics were 2.63, & 2.66 and for cotton 2.64 and 2.78. The higher the estimations of 2HG and 2HG5 the lower will be the recovery from shear deformation and this will make more inconvenience in customizing and arrangement of wrinkle at the fabric's wear. However, for this situation, the differences are noted as low, subsequently, both the cotton and casein fabrics have sensible tailor capacity [34].

Bending properties

Bending rigidity (B) is a measure of the ease with which the fabric bends. From Table 2, the bending rigidity value of casein fabric was 0.026, and for cotton was 0.0303. The bending rigidity of fabric depends upon the bending rigidity of the threads and the mobility of threads within the fabric. The lowest bending force shows and conforms to the better handling property of the material. The fiber nature, cross-section shape, and crystalline region are the other indirect factors that influence this property. Bending at low stress has a direct relationship with fabric handle, these results confirm that the casein fabric has better drape ability than the cotton. In general, a low bending rigidity is one of the most desirable properties to achieve better handle property [38]. Hysteresis of bending moment (2HB) indicates a measure of recovery from bending deformation. A lower value of 2HB is better. In this study, the 2HB value of casein and cotton were noted as 0.0252 and 0.0258, respectively, confirming the better performance of the casein over the cotton. The higher bending characteristics of the casein fabric can also be correlated with casein fabrics' lower structural tightness and thickness than the cotton fabric as mentioned in Table 3.

Compression properties

The compression properties, weight, and thickness values were provided in Table 2. Compressibility provides a feeling of bulkiness and spongy property in the fabric. The linearity of compression (LC) mainly depends on the fabric thickness and compression characteristics of the yarn. The value of LC of casein fabric was noted as 0.771, this is a little high compared to the normal cotton fabric which is noted as 0.656. This may be due to the higher bulkiness of the casein fabric. Compression energy (WC) depends upon LC and the amount of compression. The compression energy WC has been noted for casein as 0.055 and cotton as 0.042. These results confirm the higher fluffiness with the high compressibility of casein fabric compared to the cotton fabric. The compression resilience RC represents the percentage of the recovery. The compression resilience (RC) like the linearity of compression mainly depends on the fabric thickness and compression characteristics of the yarn. Casein fabrics had a recovery of 78.12% which was very high, the normal cotton fabric has a value of 77.60%. The higher the percentage better will be the fabric handle. These results were again confirmed by the difference between the values of To and Tm. Where higher the difference indicates more softness. The difference for casein fabric noted 13% and for cotton, it is 11.6%.

Surface properties

Table 2 gives the results of the surface friction coefficient value of the casein fabric. The fabric properties like the handle, comfort, and aesthetic appeal were greatly influenced by the surface characteristics of a fabric. MIU represents the coefficient of friction of the fabric surface; it is a function of the properties, yarn structure, fabric geometry and finish applied to the fabric. The MIU value of casein fabric was 0.190. This value is comparable with cotton fabric, which has a value of 0.155. The higher coefficient of friction in both knitted fabric is mainly attributed to the hairiness of the structure, which restricts the movement of the measurement probe. In this study, though no hairiness test was performed, it is mentioned based on the microscopical view of both casein and cotton fabric provided in Figure 3. The figure clearly shows the higher amount of hairiness of both the selected fabric. MMD gives the mean deviation of MIU; in other words, it was the measure of the variation of MIU. The MMD value was noted as 0.020 for casein and for cotton it is noted as 0.014. SMD represents the geometrical roughness of the fabric surface. The SMD was noted as 6.29 for casein fabric. The surface friction values suggest that the casein fabric has less amount of surface friction comparatively than cotton (6.50) fabric. This may due to the smooth surface of the casein fiber than the cotton (Figure 4).

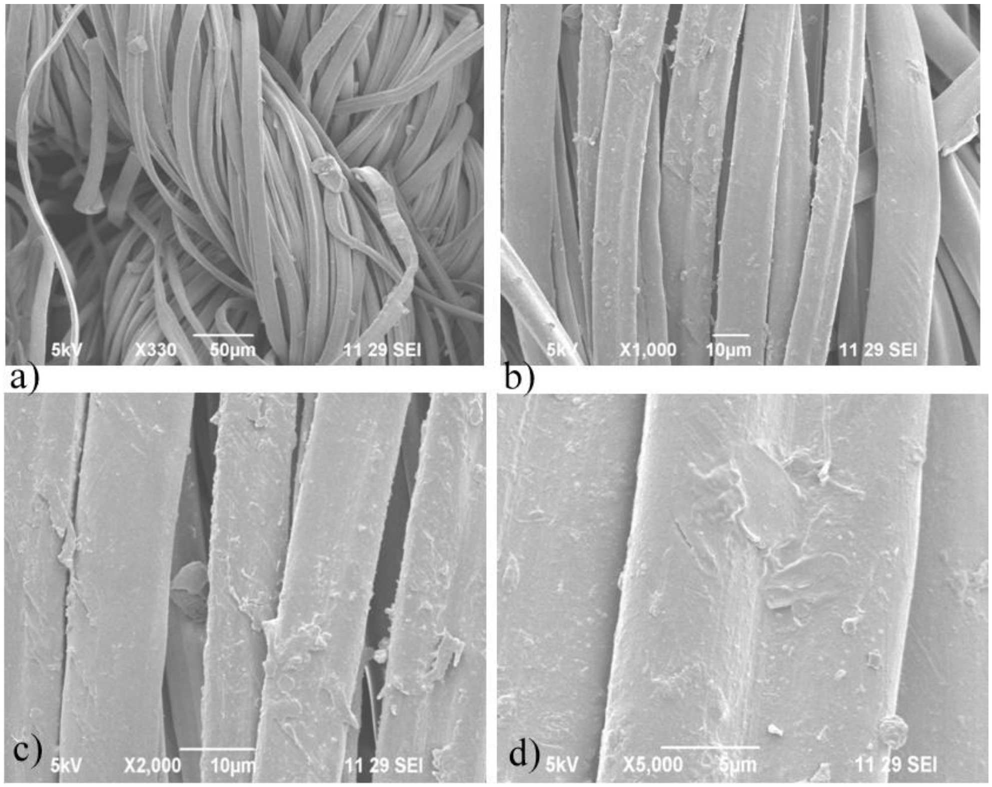


Figure 4. SEM pictures of casein fabric at different magnifications (a) 330X, (b) 1000X, (c) 2000X and (d) 5000X

Subjective evaluation of comfort

In continues to the wear trial analysis, the participants were allowed to rate the performance of the garment from 1-5, against each mentioned factor. The factors positively attribute to comfort are listed in figure 5. as far as the tactile responses are concerned, all the low-stress mechanical characteristics directly or indirectly stimulate the touch, pressure, roughness, and other mechanoreceptors of human skin. During this subjective analysis, the response from subjects was collected in the form of rating against the positively and negatively influencing tactile response to predict the low-stress mechanical properties and so the overall comfort of the garment. The overall comfort of the casein fabric was rated as best by 18 volunteers and high as 2 volunteers.

Fabric softness is a complex tactile sensation which determines the initial tactile perception of a wearer towards the clothing. Fabric softness can be related to compression and smoothness and flexibility of fabrics, depending on the fabrics being handled and end-users. The smoothness of the fabrics was related to stiffness and hardness as an opposite parameter [39-40]. Out of the twenty participants, nine rated the given fabric as best and eleven participants rated as high in terms of softness.

Warmth is another comfort feeling directly related to the thermal insulation of clothing, which is dependent on several factors: thickness and number of layers, fit, drape, fiber density, the flexibility of layers, and adequacy of closures. Researchers reported that warmness might be more dependent on fabric thickness than on weight. It has been reported that the product of fabric weight and fabric thickness was a better objective measurement for correlation with warmness and heaviness than either weight or thickness alone [39]. Warmth feeling was rated as moderate for both cotton and casein fabric by 10 subjects. This may be due to the lower thickness of both the selected fabric. Moisture absorbency of the clothing has been widely recognized as one of the most important factors contributing to discomfort sensations. Researchers found that 10-20% of moisture in the garment created high discomfort to the wearer [42] and the absorbency was highly influenced by the fiber type [43]. For absorbency of casein fabric, out of 20 participants, 10 rated as high absorbency, and other 10 respondents rated as higher than the normal intimate wear they have experienced before. Here the absorbency rating is obtained by the dryness of the fabrics (wearer comfort) and it is not the representation of moisture retention. Other parameters like the lightness of the garment, directly related to the fabric thickness and construction, snugness highly correlated with the absorbent nature, and the smoothness with surface friction. The subjective rating shows that all the above-mentioned factors were rated either as the best or high compared to their normal intimate apparel by the wearers.

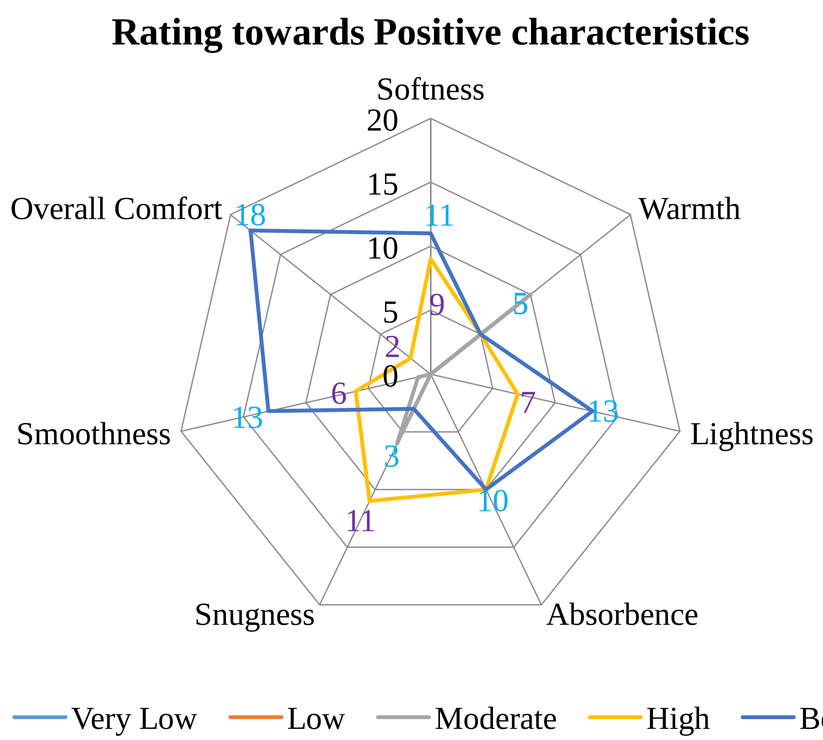


Figure 5. Subjective analysis results of positively influencing comfort parameters.

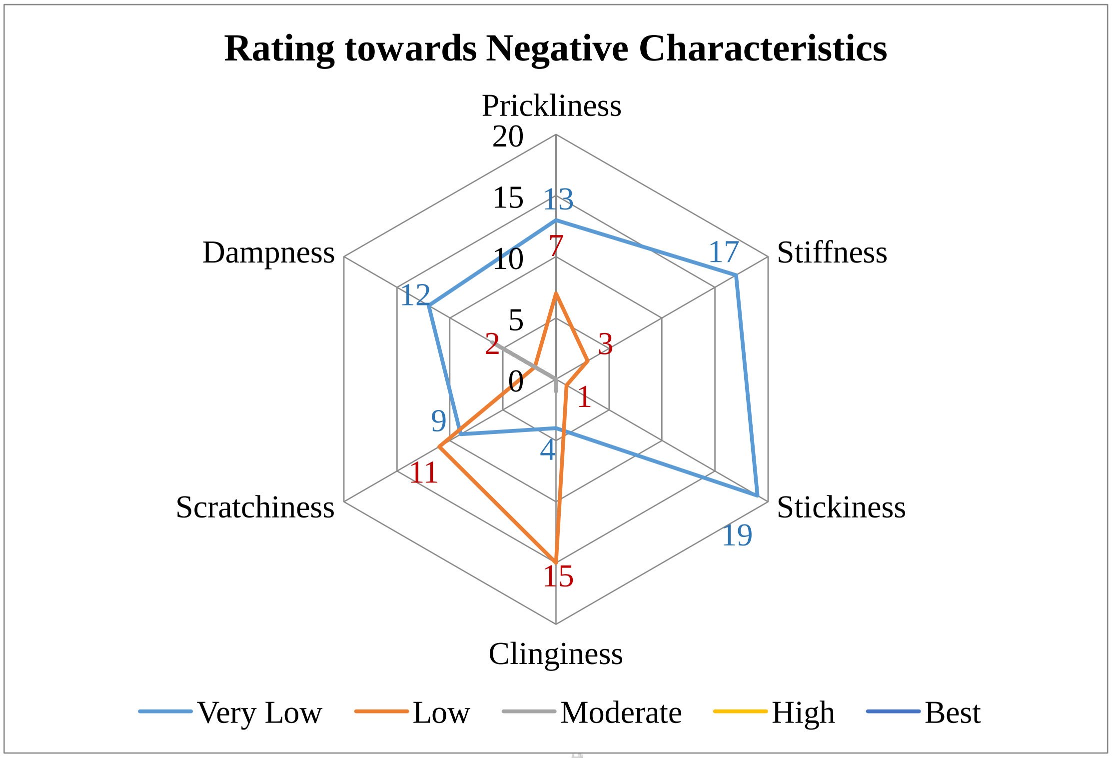


Figure 6. Subjective analysis results of negatively influencing comfort parameters.

Figure 6 represents the subjective ratings of negatively contributing factors towards fabric comfort. The selected parameters have a direct influence on the comfort characteristics of the fabric. Prickliness, the prickle sensation due to clothing is one of the most irritating discomfort sensations for clothing wear next to the skin. Individual protruding ends from a fabric surface are responsible for the problem. The sensation of fabric itchiness or prickliness depends on the diameter, fabric thickness at low and high pressures, and fabric surface roughness [44]. Scratchiness is determined by the frictional interaction between fabric and skin. The Presence of moisture at the skin surface alters the intensity of fabric roughness perceptions due to change in friction. This sensation can be felt in the fabric with textile material with poor absorbency nature. Researchers have reported that the fabric scratchiness sensation was influenced by the flexural rigidity and the friction characteristics of fabrics [41]. Clinginess of fabrics during wear is also a cause of tactile discomfort. Under conditions of profuse sweating, the fabric with poor wicking ability will create these issues. Researchers have reported that the clinging sensation is also a function of the flexural rigidity of the fabric. The lower the flexural rigidity the greater is the clinginess [41].

Fabric stiffness was very well correlated with the flexural rigidity obtained by bending hysteresis [45]. Researchers found that the agreement among three objective measurements like bending length, flexural rigidity, and drape coefficient had a good correlation with stiffness, as subjective ratings [46]. The other parameters like stickiness and dampness are related to the absorbance and clinginess of the fabric. The subjective analysis results on the negative parameters revealed that all the subjects rated the selected clothing low or very low in this category. The parameters like Prickliness, Stiffness, and Stickiness were rated very low by 13, 17, and 19 subjects respectively. This represents that the casein fabric has a very low amount of protruding fibers, low bending length, flexural rigidity, and drape coefficient. In the case of clinginess, scratchiness, and dampness most of the subjects rated as low, and few rated as very low.

Conclusions:

The application possibilities of casein fiber in apparel end-use were analyzed in this study. The casein fabric was evaluated for its moisture management properties and compared with the cotton fabric. The overall moisture management capacity Index (OMMC) of casein fabric is 0.75 and for cotton, it is 0.7. The value is rated as "Very good" OMMC value by AATCC standard. The study also identified that the air permeability values of the casein fabric are better than cotton. From the low-stress mechanical property analysis results revealed that casein fabric has higher extensibility under low stress along with lower toughness. In terms of shear property, the casein fabric had very low bending rigidity and low values for shear hysteresis (at both the angles) compared to the cotton fabric. Since the casein fabric was soft, the bending rigidity values also were very low and ensured better drape ability. The Compression value noted was a little higher for the casein fabric than cotton fabric, this may be due to the higher fabric thickness. The surface friction values of the fabric were observed similar to cotton due to the protruding fibers in the surface. However, the lower SMD values observed in the case of casein fabric than cotton as an indication of the fiber's smooth surface.

These results were also in support of the subjective analysis, where all the participants responded that the casein fabric had a better overall comfort in terms of smoothness, softness, lightness and no prickliness, lower stiffness, and no stickiness. These findings suggest that the casein fabric has a large potential in the apparel sector, specifically in the intimate wear area, based on their higher functionality and also comfort aspects.

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