Heliyon 9 (2023) e21588

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Evaluation of physical and mechanical characteristics of three-thread fleece knit fabric for their structural changes

Md. kaikobad [a,b], Md. Faisal Mahmud [a,c], Abdullah Sayam [a,d], Suman Chandra Paul [a,e], Md. Musa Ali Reza [a,f], Md. Omar Faruque [a,b], Nazmul Alam Apel [d], Md. Emdad Sarker [a,*]

[a] Department of Fabric Engineering, Bangladesh University of Textiles (BUTEX), Dhaka, Bangladesh
[b] Department of Textile Engineering, Green University of Bangladesh (GUB), Dhaka, Bangladesh
[c] Department of Textile Engineering, Ahsanullah University of Science and Technology (AUST), Bangladesh
[d] Department of Research and Development, Epyllion Group (Textile Division), Gazipur, Bangladesh
[e] Department of Textile Engineering, City University, Dhaka, Bangladesh
[f] Department of Textile Engineering, International Standard University (ISU), Dhaka, Bangladesh

ARTICLE INFO

Keywords:
Fleece fabric
Structural variation
Tuck stitch
Spirality
Pilling
Dimensional stability

ABSTRACT

The aim of this research is to explore the variations that can arise when three-thread fleece (3-TFL) fabric is manufactured with the same yarn type, count, stitch length, knitting machine gauge, and diameter but in different structural configurations. The physical and mechanical properties of 3-TFL fabrics vary depending on their structural construction, which has a significant impact on their intended usage. For this study, four distinct types of three-thread fleece fabric structures were developed titled straight, three-butt diagonal, four-butt diagonal, and double tuck 3-TFL. Fabric weight, bursting strength, shrinkage percentage, spirality, pilling, stretch and recovery percentage tests were performed on the produced samples and the results were interpreted statistically. The ANOVA study revealed a strong association between the fabric design and its properties. Although all variants of fleece fabric showed better dimensional stability, the double tuck 3-TFL fabric demonstrated a relatively high dimensional change. In addition, double tuck 3-TFL fabric showed higher fabric weight, better pilling grade, and less spirality, whereas 4-butt diagonal 3-TFL fabric exhibited higher bursting strength. This research will assist commercial knit fabric producers in the textile industry to understand the effect of structural variations on fleece fabric qualities.

1. Introduction

Fleece is one of the standard knit fabric designs and structures that continues to have wide recognition in the latest fashion concepts. This fabric has distinguishing qualities for its structure to feel comfortable, manageable, washable, and air-dryable [1]. Fleece fabrics are bulky and soft weft knitted fabrics, characterized by their thick, deep pile, and soft nap [2]. A three-thread fleece structure consists of a face yarn, a binding yarn, and a loop yarn. The structure is produced by tucking in the loop yarn into the binding yarn at different Wales position. The face yarn is only visible at the technical face side, and the loop yarn is visible at the technical backside [3].

* Corresponding author.
E-mail address: esarker@fe.butex.edu.bd (Md.E. Sarker).

https://doi.org/10.1016/j.heliyon.2023.e21588
Received 24 April 2023; Received in revised form 22 October 2023; Accepted 24 October 2023
Available online 31 October 2023

These fabrics have high thickness and mass compared to other types of knit fabrics and are extensively utilized as outdoor garments for sports and activewear. Besides, they are widely used in blankets, clothing, toys, etc. as they can keep the body warm as well as block the sun [4]. Raw materials' properties significantly affect the knitted fabric's final properties and performance. According to Farha et al., weft-knitted fabrics' propensity to the pill is influenced by the knitting technique, the raw ingredients, the linear density of the yarn, the fabric's density, and the mechanism used to spin the yarn (e.g., rotor, ring, and air-jet spinning). Additionally, it was noted that the fuzzy knitted yarn's cross-sectional structure, fiber content, composition, and degree of twist all affected the pilling resistance. The stitch-length, the raw material, and the mix utilized all impacted the bursting strength of 3-TFL [3]. Fibre orientation, morphological structure, fiber content, yarn flattening, yarn structure, fabric loop length, fabric thickness, tightness factor, and fabric structure determine the permeability qualities. As a result of their thinness, lightweight (g/m^2), incredible smoothness, and absorbency ensures higher vapor permeability. Bamboo fleece fabric loses some of its air permeability throughout the raising process. Fibre properties, fabric GSM, and fabric thickness influence the drying time [5]. Fabric properties could be improved by changing different fabric parameters and processes. The elastic recovery of fleece fabric was increased by around 9 % by altering the fleece yarn's stitch length. On the other hand, the raising operation significantly decreases the fleece fabric's elasticity. Moreover, extensibility and elastic recovery are little affected by knit and binder yarn stitch length [6].

Hossain et al. discovered that various fabric processing techniques (singeing, heat setting, stenter, and compacting) do not impact the fabric's elongation or recovery percentage. Additionally, finishing criteria had little effect on dimensional stability and spirality [2]. The mechanical strain of the brushing process significantly affects the fleece fabric's final strength. Brushing and peaching significantly alter the appearance of the fabric also. The bursting strength of the fleece fabric after brushing is increased. The space between the adjacent threads was sealed once the ejected fibers stood up. Therefore, more force was required to rip the raised fabric. After brushing, the spirality in CVC fleece fabric increased and maintained good color fastness properties [7]. Asker et al. discovered that the fabric with 50 % waste +50 % PES back yarn produced the best results in increasing fastness. Following a single passage of micro silicon pre-softening by a low-concentration softening procedure using a polyvinyl acetate-based binder and softener mixture and raising at a speed of 15 m/min, it was found that the best results were produced [8]. Fabric GSM varies when the machine gauge changes even though knitted with the same yarn count [9]. Mishra et al. concluded that the weight and thickness increase as the

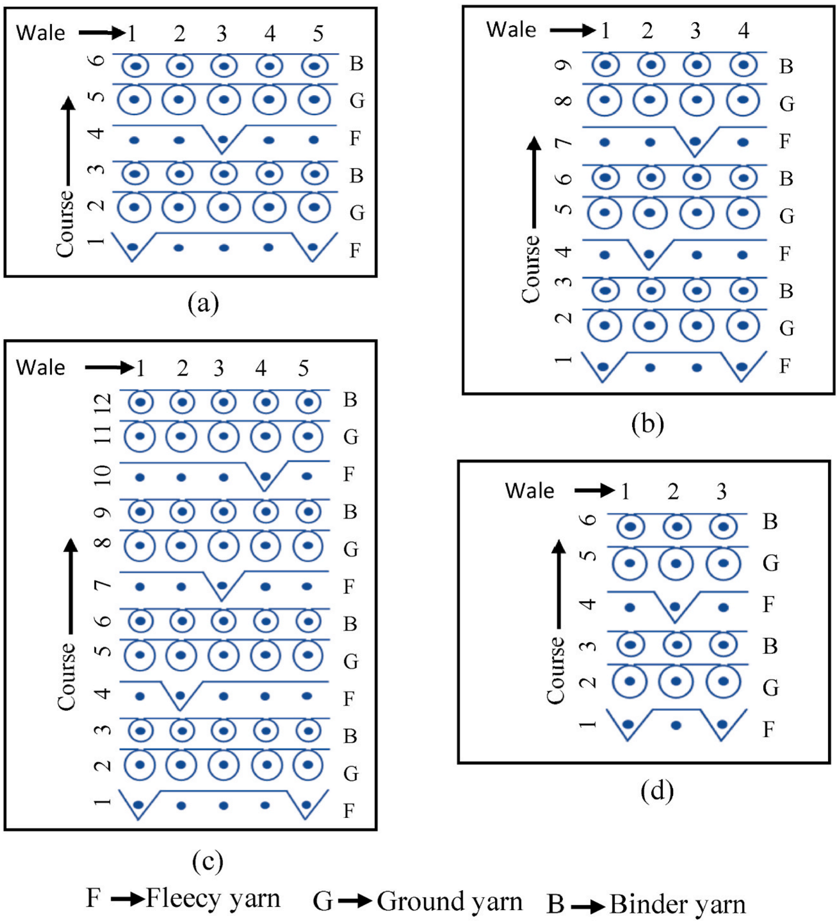

Fig. 1. Structural construction (notation diagram) of three thread fleece- (a) straight 3-TFL, (b) 3-butt diagonal 3-TFL, (c) 4-butt diagonal 3-TFL, and (d) double tuck 3-TFL.

number or percentage of tuck stitches rises. Tuck stitches also gather yarn, increasing fabric thickness in that region [10]. In another study, it was observed that the presence of tuck and float stitches has a major impact on the fabric's drape ability for a particular structure, extensibility along the breadth, shrinkage along the length, thickness, areal density, and low-stress mechanical properties [11]. According to Değirmenci et al., rather than stitch length, variations in loop shape had an enormous impact on changes in knitted textiles' dimensions [12]. The spirality grows significantly when the number of working feeders increases while maintaining a constant machine diameter. Moreover, the stitch length and yarn tension impact the fabric's spirality [13]. Structure of fleece fabric is very influential yet a largely overlooked parameter in the literature. Knitting industries employ a wide variety of structures varying upon position and number of tuck and miss loops in the structure as illustrated in Fig. 1. Proper selection of fleece structure is prerequisite since it plays a pivotal role in attaining brush quality, avoiding cross-staining in multi-coloured garment style, achieving appropriate fabric weight, pilling, dimensional stability, stretch and recovery asked the by the buyer without causing any change in raw material, knitting parameters and hence production cost. The relationship between bursting strength with structure is another crucial issue since these garments are predominantly used for outdoor activity. All these factors are indispensable cornerstone for ensuring the proper quality of fleece fabric and simultaneously increasing the profit margin of a textile mill. Previously, many studies have been done on the effects of altering the raw yarn and fabric composition, improvising pre- and post-processing sequences on the characteristics of fleece knit fabrics. Yet, a search of Scopus and World of Science articles reveals that prior studies have overlooked the structural significance of fleece fabric. To minimize this research gap, this study is designed to investigate the impact of structural change on the physical and mechanical characteristics of three-thread fleece knit fabric. The study will present keen insights regarding performance of different structures of fleece fabric which would mend the trajectory for future research and development.

2. Materials and method

2.1. Materials

The materials, yarn count, loop length, spinner, lot, twist, and count strength product (CSP) for ground yarn, binding yarn, and fleecy yarn of three-thread fleece fabric are all shown in **Table-1** in that order. The binding yarn was produced using filament (36F), while the face and fleecy yarns were produced by ring spinning. In this study, yarn types were the same for all produced samples.

2.2. Machine

All sample fabrics have been developed using several types of machinery and are listed in **Table-2**.

2.3. Sample preparation

2.3.1. Knitting process

The sample fabrics were produced at Epyllion Fabric Ltd. using a fleece circular knitting machine. Four different 3-TFL fabric structures were developed to conduct this research: straight, 3-butt diagonal, 4-butt diagonal, and double-tuck 3-TFL. All knitting parameters in **Table-2,** including yarn type, yarn count, stitch length, number of feeders, machine gauge, diameter, and the total number of needles per cylinder, were the same for each sample **(Table-1)**; only their structural construction was changed, as shown in **Figure-1** (1(a) for straight 3-TFL, 1(b) for 3-butt diagonal 3-TFL, 1(c) for 4-butt diagonal 3-TFL, and 1(d) for double tuck 3-TFL fabric). The values of repeat size and tuck loop density of these aforementioned four types of fleece fabric have been shown in **Table-3**. Needle and cam arrangement of these 3-TFL fleece structures have been depicted in **Figure-2** (2(a) for straight 3-TFL, 2(b) for 3-butt diagonal 3-TFL, 2(c) for 4-butt diagonal 3-TFL, and 2(d) for double tuck 3-TFL fabric). Following knitted fabric production, the samples were subjected to a 24-h conditioning period (21 ± 2)^{o}C temperature and (65 ± 2)% relative humidity (RH) to attain a dry-relaxed state before pre-treatment.

2.3.2. Finishing process

Following relaxation, the fabric was subjected to a 45-min combined scouring and bleaching treatment at 95 °C. H_2O_2 and caustic soda (NaOH) were utilized as bleaching and scouring agents, respectively, and other auxiliary agents listed in **Table-1** were also used. After that, the fabric was slit along the lengthwise direction. The fabric was then finished using an LK stenter machine with a 64-inch fabric diameter, 40 % over feed, 140 °C temperature, and 8 m/min fabric speed. 10 g/l GSP cone was employed during finishing to

Table 1
Experimental materials.

Yarn parameters	Ground yarn	Binder yarn	Fleecy yarn
Raw materials	Cotton (Combed compact)	Polyester (Slight intermingled Raw)	CVC (80/20)
Yarn count (Ne)	30	70.87	10
Loop length (mm)	4.45	3.00	1.65 (2.00 for Double Tuck 3TFL)
Spinner	Sagar, India	Zhejiang, China	Square, Bangladesh
Twist	Z	–	Z
CSP	2259	–	2413

Table 2
Machine and Process details.

Knitting machine		Dyeing machine		Stentering machine			Brushing machine		Shearing machine	
Parameters	values	Parameters	values	Parameters	Values (Before brush)	Values (After brush)	Parameters	values	Parameters	values
Brand	Lisky	Brand & Origin	Labpro, China	Brand	Lk	Lk	Brand	Lafers	Brand	Lafers
Origin	Taiwan	Wetting Agent	1 g/L	Origin	Taiwan	Taiwan	Origin	Italy	Origin	Italy
Diameter (inch)	30	Sequestering Agent	0.3 g/L	Temperature	140 °C	140 °C	Fabric speed	25 m/min	Fabric speed	40 m/min
Gauge	20	Detergent	0.1 g/L	Fabric Width	64 inches	64 inches	Pile roller diameter	85 cm	Lower tension	16 kg
		Anti creasing agent	0.5 g/L							
No. of feeder	96	Caustic soda	1.5 g/L	Over-feed	40 %	20 %	Counter pile roller diameter	85 cm	Taker in tension	8 kg
		H_2O_2	2 g/L							
Ground yarn tension	8 CN	Peroxide Stabilizer	0.15 g/L	No. of burners	8	8	No of pile roller	14	Plaiter tension	5 kg
Binder Yarn tension	7 CN	Per oxide killer	0.1 g/L	Chemical (GSP cone)	10 gm/l	10 gm/l	No. of counter pile roller	14	Lower blade shearing intensity	3.52 mm
		p^H	11	Back padder pressure	2.5 kg	2.5 kg	Lower tension	6 kg		
Loop yarn tension	12 CN	Temperature	95 °C	Front padder pressure	3 kg	3 kg	Upper tension	8 kg	Upper blade shearing intensity	4.01 mm
		Time	45 min							
RPM	22	M: L	1:8	Fabric Speed	8 m/min	10 m/min	RPM	120	RPM	700

Table 3
Fabric specification.

Fabric parameters	Straight 3-TFL fabric	3-butt diagonal 3-TFL fabric	4-butt diagonal 3-TFL fabric	Double tuck 3-TFL fabric
Composition	78 % Cotton 22 % Polyester	78 % Cotton 22 % Polyester	78 % Cotton 22 % Polyester	78 % Cotton 22 % Polyester
Stitch Length (mm) (G/B/F)	4.45/3.00/1.65	4.45/3.00/1.65	4.45/3.00/1.65	4.45/3.00/2.00
Repeat Size (Course Wale)	6 4	9 3	12 4	6 2
Grey Width (inch)	73	74	76	82
Finished Width (inch)	64	63	66	65
Grey GSM	307	310	276	330
Finished GSM	346.3	339.6	330.3	370
Grey CPI	37	38	36	40
Grey WPI	26	25	26	24
Finished CPI	40	39	39	42
Finished WPI	29	29	28	28
Grey Stitch Density (G. CPI x G. WPI)	962	950	936	960
Finished Stitch Density (F. CPI x F. WPI)	1160	1131	1092	1176
Shape Factor (Grey)	1.42	1.52	1.38	1.67
Shape Factor (Finished)	1.38	1.34	1.39	1.50
Tuck Loop Density	8.33 %	11.11 %	8.33 %	16.67 %

enhance adsorption properties. The fabric's backside was then brushed in a lafer brushing machine with 14 pile rollers and 14 counter pile rollers at 25 m/min speed. The fabric was again finished using a stenter machine with a 64-inch fabric diameter, 20 % overfeed, 140 °C temperature, and a 10 m/min speed. Finally, a lafer shearing machine was used to shear the fabric's brush side at 40 m/min, with the top and lower blades' shearing intensities set at 4.01 mm and 3.52 mm, respectively. The samples were subjected to 24-h conditioning at (21 ± 2)°C temperature and (65 ± 2)% RH to achieve a dry-relaxed state. The manufacturing process of three-thread fleece fabric is illustrated in **Figure-3**.

The front sides of these four variants of 3-TFL are identical, yet the back sides are very different. The straight and double-tuck 3-TFL fabrics have a linear pattern on the reverse side; however, due to the higher tuck density in the double-tuck fabric, the floating loop is considerably smaller than in the straight 3-TFL fabric. Both 3-butt diagonal 3-TFL and 4-butt diagonal 3-TFL fabrics exhibit skew on their backsides, but 4-butt diagonal 3-TFL fabric exhibits considerably more significant skew than 3-butt diagonal 3-TFL fabric. The developed four types of 3-TFL fabric samples' appearance are shown in **Figure-4** (4(a) for straight 3-TFL, 4(b) for 3-butt diagonal 3-TFL, 4(c) for 4-butt diagonal 3-TFL, and 4(d) for double tuck 3-TFL fabric) and specifications are mentioned in **Table-3**.

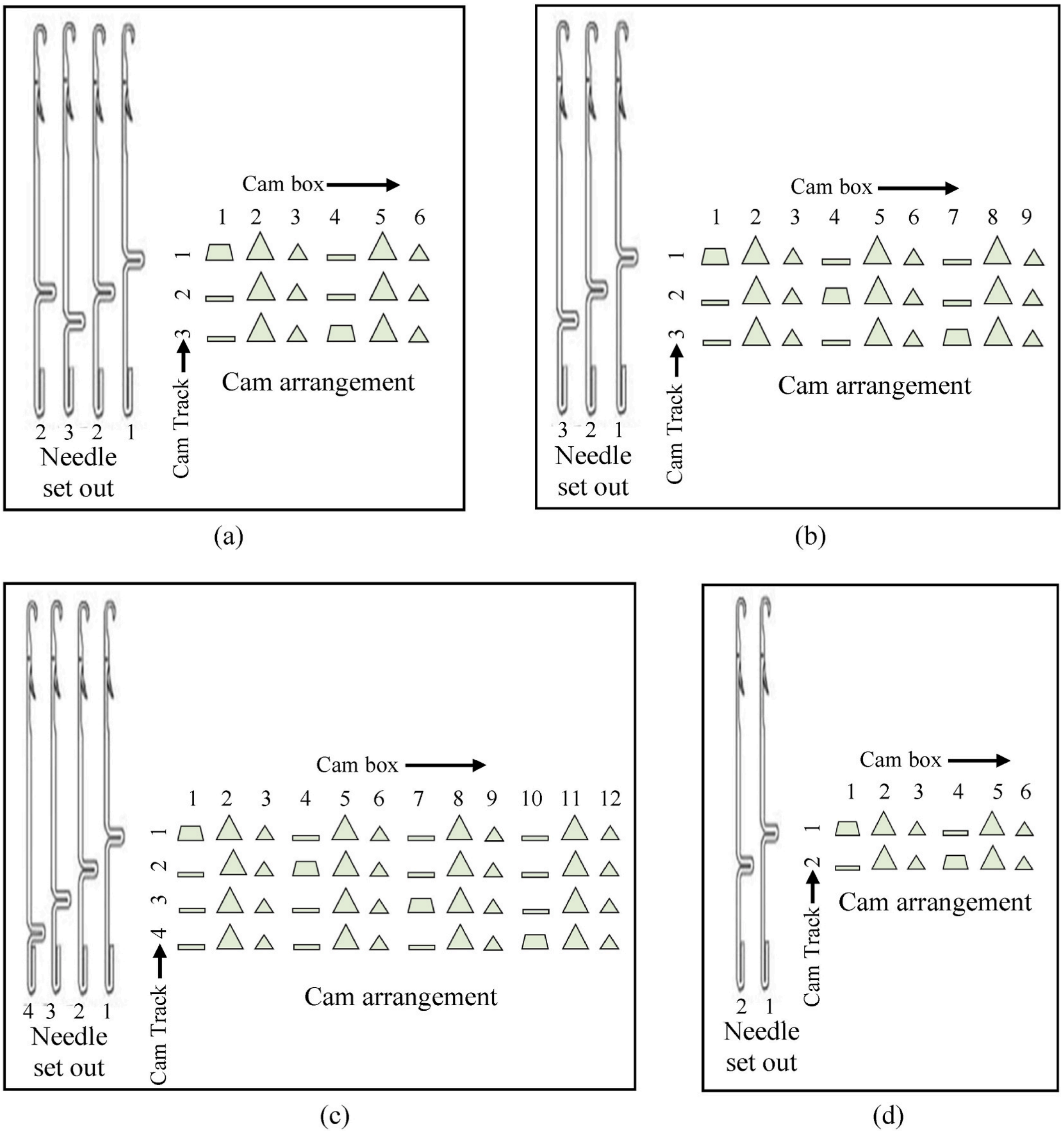

Fig. 2. Needle and cam arrangement of three thread fleece- (a) straight 3-TFL, (b) 3-butt diagonal 3-TFL, (c) 4-butt diagonal 3-TFL, and (d) double tuck 3-TFL.

2.4. Testing methods

A variety of tests that were carried out to evaluate the performance of all the finished fleece fabrics which have been listed in **Table-4**.

3. Results and discussion

3.1. Bursting strength test

Several factors, including yarn parameters, the loop length and shape, change the bursting strength of fleece fabric [14–16]. Fabric structure, the number, and the position of tuck loops are essential parameters for bursting strength. Still, most importantly, the position of tuck loops is more decisive than the number of tuck loops. However, increasing the number of tuck loops in a design increases the tension on the yarn, which can reduce the bursting strength. But when tuck loops are formed on adjacent needles, the samples show more bursting strength [16]. **Figure-5** shows that the 4-butt diagonal 3-TFL has a higher bursting strength than the straight and 3-butt diagonal. Double tuck 3-TFL shows the lowest bursting strength because of its structure's common diagonal distribution of tuck loops and higher tuck density.

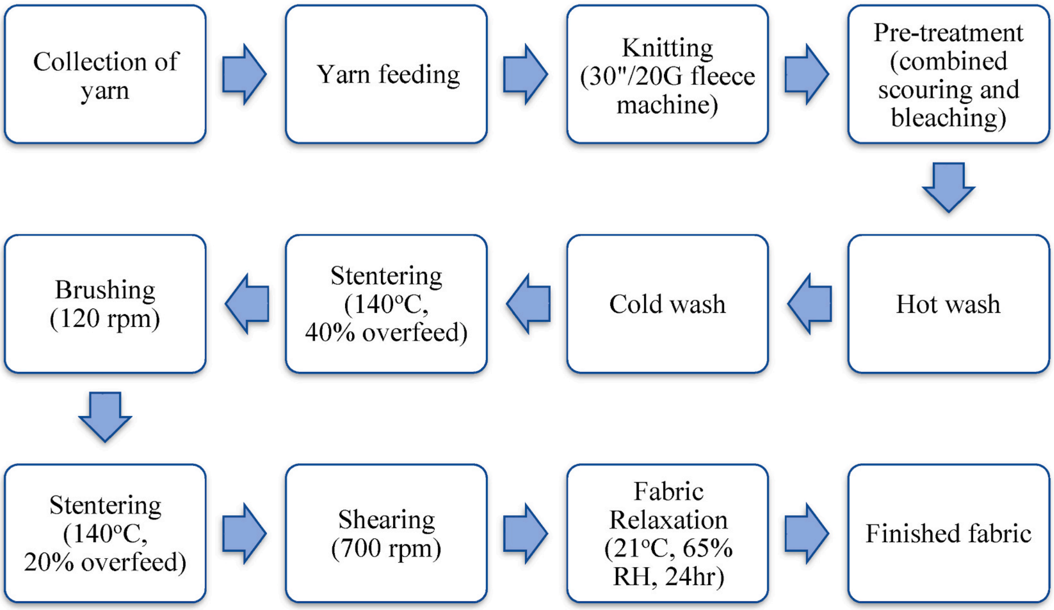

Fig. 3. The manufacturing process of three-thread fleece fabric.

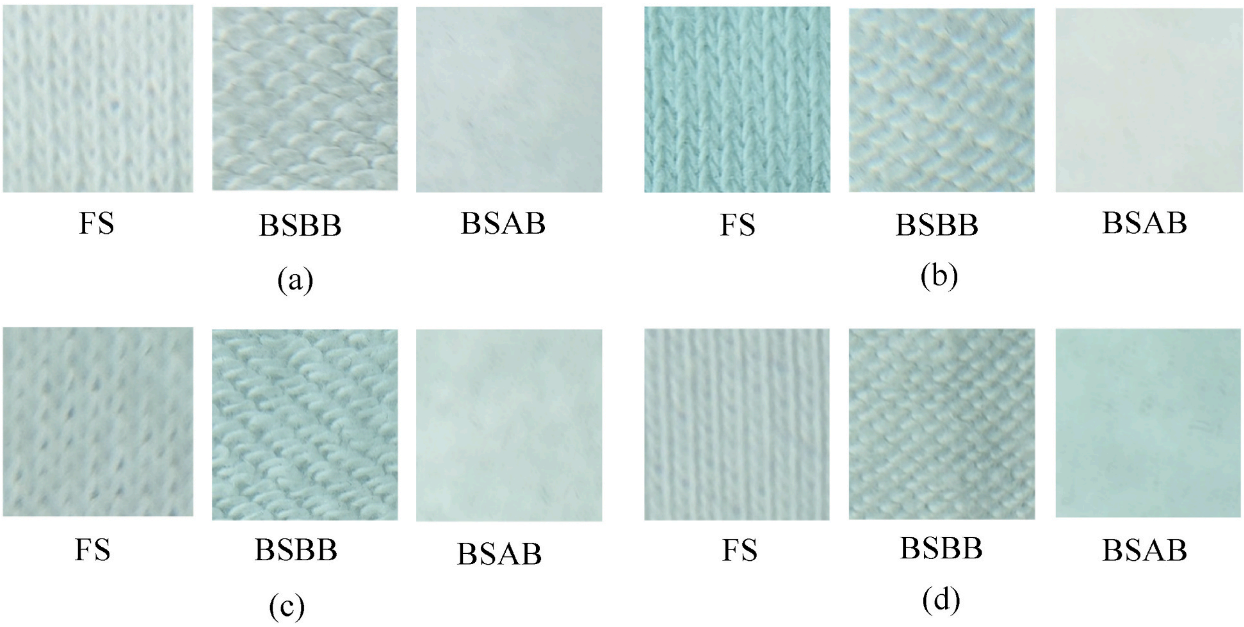

Fig. 4. Appearance (10x) of three thread fleece fabric - (a) straight 3-TFL, (b) 3-butt diagonal 3-TFL, (c) 4-butt diagonal 3-TFL, and (d) double tuck 3-TFL.

The ANOVA table demonstrates the relevance of the structural variation of different samples on bursting strength. All the results were subjected to an ANOVA, and the outcomes are presented in Table 5. It is evident from these test results' extremely high F values and extremely low P values that structural variation significantly impacts the fabric's bursting strength.

3.2. Fabric weight

Fabric weight is the blueprint of fabric quality [17]. The factors influencing the fabric's weight are the yarn count, loop length, machine gauge, thread densities, and loop types. The fabric's accumulation of more tuck loops is significantly thicker than a 100 % knit stitch fabric [10,11]. The double tuck 3-TFL sample's fabric weight was greater (370 g/m^2) and lower for the 4-butt diagonal 3-TFL

Table 4
Testing method and equipment.

Tests	Methods	Sample size	Equipment
Bursting Strength	ISO 13938-2	7.2 cm^2	Bursting Strength Tester
Fabric Weight	ASTM D3776	–	GSM cutter, Electronic Balance
Dimensional Stability	AATCC-135-2018	50 × 50 cm^2	Glass Template, Washing Machine, Tumble Dryer
Stretch and Recovery	ASTM D2594-04 (R2016)	18 × 2 $inch^2$	Stretch and recovery Tester
Spirality	AATCC-135-2018	50 × 50 cm^2	Glass Template, Washing Machine, Tumble Dryer
Pilling	ISO 12945-2-2000 cycles	140 mm circumference	Martindale Wear and abrasion Tester

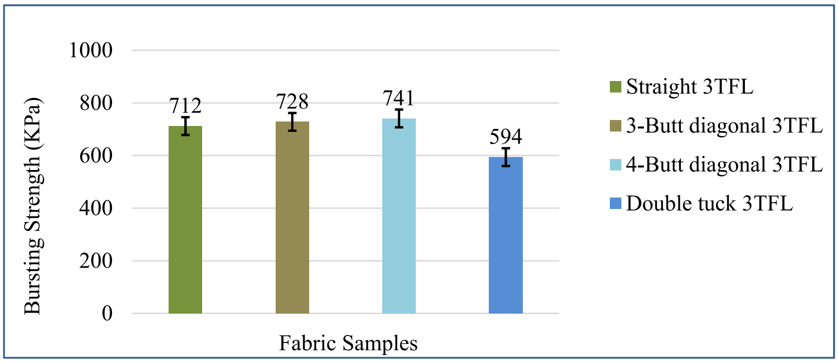

Fig. 5. Bursting strength of different samples.

Table 5
ANOVA of bursting strength.

Source of Variation	SS	df	MS	F	P-value
Between Groups	68443.75	3	22814.58	5231.20	3.86E-24
Within Groups	69.78	16	4.36		
Total	68513.53	19			

SS=Sum of Squares, *df* = degree of freedom, *MS* = Mean Square.

sample (330.3 g/m^2). The fabric weights for 3-butt diagonal and straight 3-TFL samples were 339.6 g/m^2 and 346.3 g/m^2, respectively. The tuck loop density of double tuck fleece fabric is 16.67 %, and the fleecy yarn stitch length is 2.00 mm, much greater than the other samples and thus demonstrating higher fabric weight. The position of the tuck loop in the adjacent needle reduces the fabric weight [16]. The tuck loop density of the 3-butt diagonal 3-TFL fabric is 11 %, which is higher than straight 3-TFL fabric, but this fabric was lighter (339.6 g/m^2) due to the diagonal position of tuck loops. In addition, the 4-butt diagonal 3-TFL fabric showed the lowest weight (330.3 g/m^2) due to its low tuck density (8.33 %) and diagonally tuck loops on the adjacent needles.

The ANOVA table demonstrates the impact of the structural variation of different samples on areal density (Table 6). All the results were subjected to an ANOVA, and the outcomes are presented in Table 6. These test results have high F and extremely low P values, demonstrating the importance of the influence of structural variation on fabric GSM.

3.3. Dimensional stability

The fiber type, yarn linear density, twist, loop length, loop type (knit, tuck, and miss), morphological structure, water absorption, finishing process, and fabric width all have a significant relationship to control the dimensional changes of a knitted fabric [12]. According to international standards, shrinkage or growth values of up to ±3 % are within acceptable ranges (AATCC 135–2018). When the stitch density of the fabrics decreases, loops become more susceptible to movement, and the dimensional stability of the fabrics reduces as well. Simultaneously, the tuck loops in the fleecy fabrics caused a lower dimensional change (towards negative

Table 6
ANOVA of fabric GSM.

Source of Variation	SS	df	MS	F	P-value
Between Groups	4311.65	3	1437.21	530.02	3.22E-16
Within Groups	43.35	16	2.71		
Total	4355.04	19			

values) in the fabric's length values [11].

As shown in **Figures-6 & 7**, the shrinkage properties of these fleece fabrics were around ± 3 %. Hence it was judged that all the fabrics were suitable for the standard based on these. But, only the double tuck 3-TFL fabric showed a relatively significant dimensional change (after 1st wash −3.2 % & after 2nd wash −4.7 %) in the lengthwise direction.

In Table 7, the ANOVA findings are presented. Here, the P values have been extremely low and within the required range, yet the F value has been extremely high for all intervals (after the first and second wash). The high F value indicates that while there is slight variation among samples from the same group (in this case, all samples of the tested fabric), there is significant variation among the various groups (e.g., specimens of straight, 3-butt diagonal, 4-butt diagonal, double tuck 3-TFL). It shows that the test findings of the samples differ significantly. It demonstrates that the structural variations greatly impact the shrinkage property. The low P value further indicates the reliability of the factor's relevance.

3.4. Stretch and recovery

The yarn type, twist, fabric structure, loop type, and loop length significantly affect fabric stretch and recovery. Among those, the tuck loop decreases the fabric's length and longitudinal extensibility because of the higher yarn tension on the held and tuck loops, which causes them to grab yarn from the adjacent knitted loops, reducing them [11]. The retained loops are pulled downward by tuck loops, causing them to spread out and make more yarn available for extensibility along the fabric's width. As a result, the width of the fabric expands. **Figure-8** illustrates how the fabric stretch percentage varies for different types of fleece fabric.

The fabric stretch percentage appeared greater in the course direction than in the wale direction for all samples. It was observed that the fabric exhibited greater stretch in the course direction, and showed less stretch in the wale direction. In addition, the stretchability of the 3-butt diagonal and 4-butt diagonal 3-TFL samples were higher in course-wise direction than the straight and double tuck 3-TFL samples and vice-versa in the wale direction.

The ANOVA table demonstrates the relevance of the structural variation of different samples on stretch properties (Table-8). All the results were subjected to an ANOVA, and the outcomes are presented in Table 8. It is evident from these test results' extremely high F and extremely low P values that the structural variation significantly impacts the fabric's stretch % of the course and wales direction.

Because of floating yarns, adjacent wales are compressed closer together, reducing width-wise elasticity and enhancing fabric stability. The usage of floating yarn increased wale-wise and lowered the course-wise elasticity of knitted fabrics. Conversely, to loop overlapping, yarn floating affects fabric stretchability more in the course-wise direction than the wale-wise direction [11]. The fabric growth recovery percentages have been demonstrated in **Figure-9** in both the course-wise and wale-wise directions. It was demonstrated that the range of the Percentage recovery of fabric growth in the course-wise and wale-wise directions was 6.7–15.5 and 2.1 to 8.5, respectively. For varying the number of float loops in the developed samples, the recovery was higher towards the course-wise direction, and it was highest (15.5 %) in the straight 3-TFL fabric.

The ANOVA table demonstrates the impact of the structural variation on the growth properties (Table-9). It is evident from all of these test results extremely high F values and extremely low P values that the structural variation significantly impacts the growth recovery percentages of the fabric.

3.5. Fabric spirality

It is important to know that the spirality from the yarn and the spirality from the number of feeders in the machine can combine to create more skew or offset the skew. Fabrics were made of similar yarn, the same number of twists, and the same number of feeders, and the machine rotational direction was the same also [13]. Spirality percentages among all types of fabrics may vary for stitch density and the number of tucks in a fabric design. The greater number of tuck loops in a design rises the fabric weight but lessens the stitch movement in the fabric [18,19]. The washing of fabric also increases the spirality [20]. The maximum spirality percentage

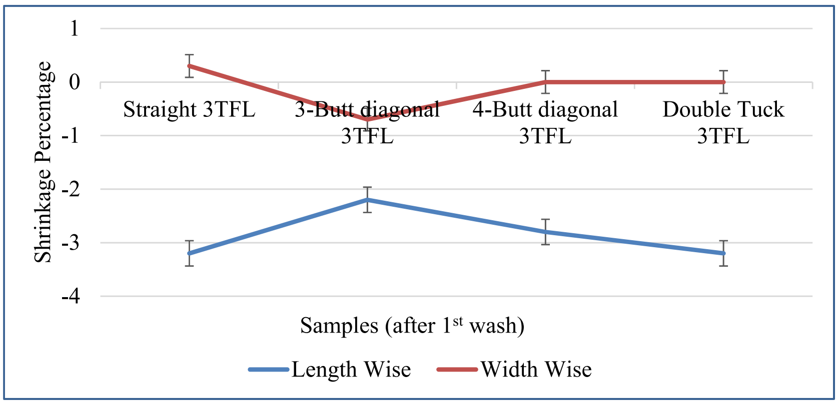

Fig. 6. Shrinkage properties (after 1st wash).

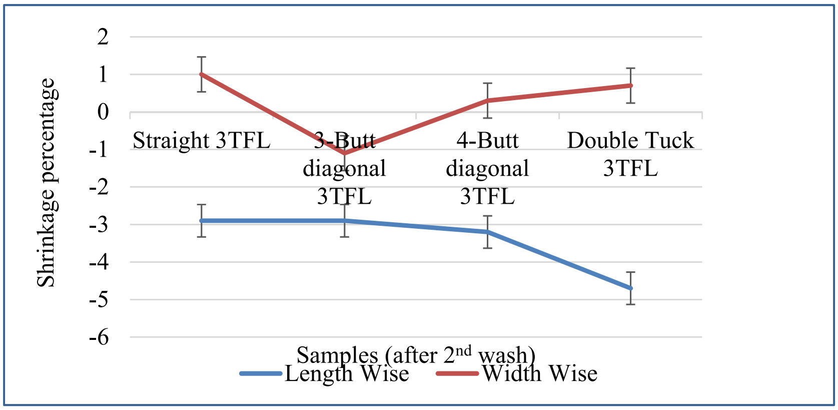

Fig. 7. Shrinkage properties (after 2nd wash).

Table 7
ANOVA of the Sample's dimensional stability.

Interval	Parameter	Source of Variation	SS	df	MS	F-Value	P-value
After 1st wash	Length wise	Between Groups	2.63	3	0.87	54.91	1.21E-08
		Within Groups	0.26	16	0.02		
		Total	2.89	19			
	Width wise	Between Groups	1.89	3	0.63	3596	7.72E-23
		Within Groups	0.03	16	0.0002		
		Total	1.90	19			
After 2nd wash	Length wise	Between Groups	9.9	3	3.3	130.001	1.91E-11
		Within Groups	0.41	16	0.03		
		Total	10.31	19			
	Width wise	Between Groups	12.94	3	4.31	2721.89	7.13E-22
		Within Groups	0.03	16	0.002		
		Total	12.96	19			

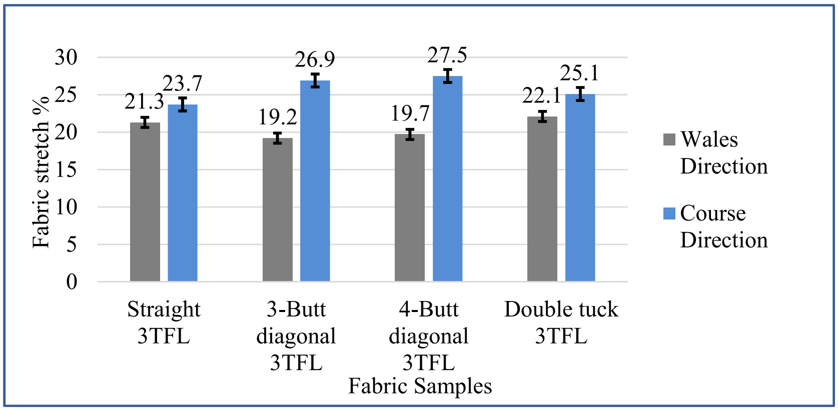

Fig. 8. Fabric stretch percentage.

(8.5–9.0 %) is found in the 4-butt diagonal 3-TFL sample, while the minimum (1.0–1.5 %) is found in the double tuck 3-TFL sample shown in Figure-10. Double tuck and 3-butt diagonal 3-TFL fabric have a tighter tuck density than the other two in the design. More closed dense loops cannot be distorted in both wale-wise and course-wise direction [6]. On the other hand, Straight and 4-butt diagonal 3-TFL showed less weight, stitches are less densely made in the structure and showed higher spirality, consequently for loose structure. After the 1st to 3rd wash, skewness merely rises by 0.5 % for double tuck and 3-butt diagonal 3-TFL specimens and by 1 % for straight and 4-butt diagonal 3-TFL specimens, considered to be negligible percentages.

Table-10 presents the ANOVA results. Here, the P values have been extremely low and within the required range, yet the F value has been extremely high for all intervals (after the first and second wash). The high F value indicates slight variation among samples

Table 8
ANOVA of sample's stretch properties.

Parameters	Source of Variation	SS	df	MS	F-Value	P-value
Wale wise	Between Groups	27.54	3	9.18	14.54	7.83E-05
	Within Groups	10.1	16	0.63		
	Total	37.64	19			
Course wise	Between Groups	45	3	15	17.71	2.45E-05
	Within Groups	13.55	16	0.85		
	Total	58.55	19			

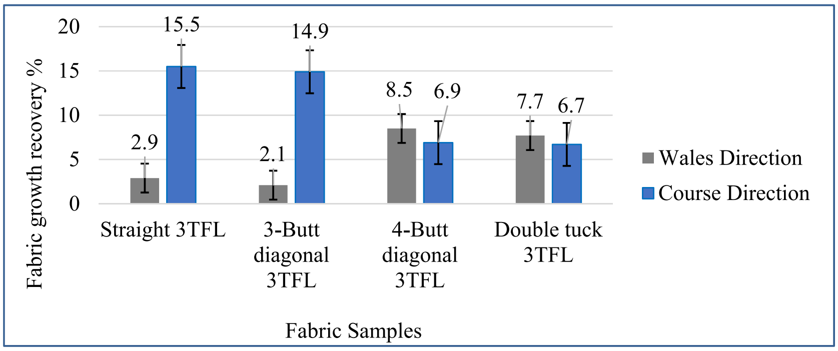

Fig. 9. Fabric growth recovery percentage.

Table 9
ANOVA of fabric growth recovery percentages.

Parameters	Source of Variation	SS	df	MS	F	P-value
Wale	Between Groups	404.55	3	134.85	566.18	1.91E-16
	Within Groups	3.81	16	0.24		
	Total	408.36	19			
Course	Between Groups	353.8	3	117.93	436.79	1.49E-15
	Within Groups	4.32	16	0.27		
	Total	358.12	19			

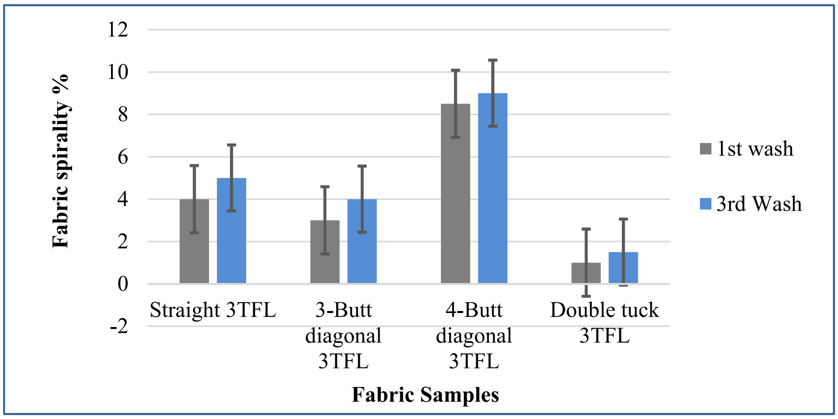

Fig. 10. Spirality properties of different types of samples.

from the same group (for instance, all tested fabric samples). In contrast, there is a significant variation between groups (e.g., specimens of straight type, 3-butt, 4-butt, double tuck). It shows that the test findings of the samples differ significantly. It demonstrates that the structure variation of fabrics greatly impacts the spirality of the fabric. The low P value further proves the reliability of the factor's relevance.

Table 10
ANOVA of fabric spirality.

Interval	Source of Variation	SS	df	MS	F-value	P-value
After first wash	Between Groups	150.93	3	50.31	1110.95	9.04E-19
	Within Groups	0.73	16	0.05		
	Total	151.66	19			
After 3rd wash	Between Groups	145.94	3	48.64	654.72	6.04E-17
	Within Groups	1.18	16	0.07		
	Total	147.13	19			

3.6. Pilling and abrasion resistance

Pilling characteristics influence both the appearance and the longevity of a garment. In ISO 12945–2:2000 cycles were utilized to evaluate the backside appearance, followed by 500, 1000, and 2000 testing device cycles on the scale of numeric values 1, 2, 3, 4, and 5 for very severe pilling, severe pilling, moderate pilling, slight pilling, and no pilling respectively. The findings emphasize the importance of selecting fleecy knitted fabrics for pilling rates significantly affected by the fabric pattern [21]. The pilling resistance of knit fabrics is influenced by the number of tuck stitches, their placement, and the length of the structural cell stitch or a knitted construction that is tight and compact [22]. It has been discovered that the greater the density of tuck loops, the greater the resistance to pilling, and the diagonal lay of tuck loops fabric showed a lower pilling resistance [23,24]. The samples were tested, and results have shown that the fleece fabric samples after 500 cycles pilling resistance ratings of 3–4 are moderate to slight pilling. This may have happened due to the lower cycle number with minimum friction. After 1000 cycle rupture on the fleece fabric surface found with a grade 3, a moderate pilling resistance was demonstrated. But after 2000 revolutions, the tested results have shown lower pilling resistance with a grade around 2–3. Apart from the straight 3-TFL and 4-butt diagonal 3-TFL, the tuck loop density of double tuck and the 3-butt diagonal 3-TFL fabric is 16.67 % in the repeat size. The fabric design has a greater number of tuck densities resulting in the fabric having excellent pilling resistance. As the diagonal position of tuck loops reduces the tuck loops densities in fleece fabric and increases the porous and loose structure, the 4-butt diagonal and straight 3-TFL fabric have shown comparatively lower pilling resistance.

4. Conclusions

This study investigated how different mechanical and physical properties of a fleece fabric were affected by modifying the tuck position and repeat size. It was concluded from the study that tuck loop position and density in the fleece structures were the most influential attributes to change the fabric properties. The 4-butt diagonal fabric had the lowest GSM but the highest bursting strength, growth, and spirality percentage among other structures, whereas the double tuck 3-TFL has the largest areal density and the lowest spirality percentage and the 3-butt diagonal 3-TFL fabric exhibits great results with the lowest shrinkage percentage of all the samples. The study revealed that double tuck 3-TFL structures will be more suitable for achieving excellent brush quality, better pilling grade, less spirality and higher voluminous fabric imparted by high tuck loop density (16.67 %) compared to other structures. Consequently, The ANOVA analysis showed a significant relationship between the fabric design and its properties. The findings of this study are anticipated to open a new window of opportunities to improve the design and performance of fleece fabrics to meet customer requirements. Furthermore, it will assist commercial manufacturers in comprehending the structural significance of fleece fabric qualities.

Limitations and future recommendations

Double tuck 3-TFL fabric's fleecy yarn loop length was slightly longer due to its higher tuck density (16.67 %) than other types of fleece fabric and had to be kept at 2.00 mm instead of 1.65 mm. The following recommendations for further study can be made in light of the work:

- Due to structural modifications in fleece fabric, changes in fabric thickness, air permeability, moisture management, thermal resistance, and ultraviolet protection performance can be studied.
- Equations can be developed to predict the fabric properties through simulation.
- Microscopic analysis may be done.

Funding statement

This research received no specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

CRediT authorship contribution statement

Md. kaikobad: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing. **Md. Faisal Mahmud:** Formal analysis, Investigation, Validation, Visualization, Writing – original draft, Writing – review & editing. **Abdullah Sayam:** Data curation, Formal analysis, Investigation, Validation, Visualization, Writing – review & editing. **Suman Chandra Paul:** Formal analysis, Investigation, Validation, Visualization, Writing – original draft. **Md. Musa Ali Reza:** Formal analysis, Investigation, Validation, Visualization, Writing – original draft, Writing – review & editing. **Md. Omar Faruque:** Formal analysis, Investigation, Validation, Visualization, Writing – original draft. **Nazmul Alam Apel:** Project administration, Resources. **Md. Emdad Sarker:** Conceptualization, Data curation, Formal analysis, Investigation, Project administration, Supervision, Validation, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

The authors thank Epyllion Group for their technical support in knitting, dyeing, and finishing the experimental fabrics.

References

[1] Md.A. Rassel, M.M.U. Hoque, An investigation into the dimensional stability of 100% cotton fleece knit fabric | journal of ELT and education, J. ELT Edu. 2 (2019) 41–47.

[2] Md.S. Hossain, M.D.M. Islam, S.C. Dey, N. Hasan, An approach to improve the pilling resistance properties of three thread polyester cotton blended fleece fabric, Heliyon 7 (2021), e06921, https://doi.org/10.1016/j.heliyon.2021.e06921.

[3] F.I. Farha, S.A. Smriti, M.A.A.H. Sarker, F. Xu, Fibrous impact on several primary characteristics of three-thread fleece fabric, AATCC J. Res. 6 (2019) 30–38, https://doi.org/10.14504/ajr.6.5.5.

[4] S. Jin, Y. Chen, J. Yin, Y. Li, M.K. Gupta, P. Fracz, Z. Li, Three-dimensional reconstruction of fleece fabric surface for thickness evaluation, Electronics (Switzerland) 9 (2020) 1–12, https://doi.org/10.3390/electronics9091346.

[5] A.A. Badr, A. El-Nahrawy, Moisture properties of raised 3-thread fleece fabric knitted with different face and fleecy yarns, Alex. Eng. J. 55 (2016) 2881–2892, https://doi.org/10.1016/j.aej.2016.06.021.

[6] M.S. Hossain, S. Alimuzzaman, A.N. Md Ahsanul Haque, Improvement of elastic property of circular weft knit three-thread fleece fabric by changing stitch length, AATCC J. Res. 8 (2021) 25–32, https://doi.org/10.14504/ajr.8.1.4.

[7] Md. Touhiduzzaman, R. Kmm, Effects of raising and sueding on the physical and mechanical properties of dyed knitted fabric, J. Textil. Sci. Eng. 6 (2015) 1–5, https://doi.org/10.4172/2165-8064.1000228.

[8] Ğ. Asker, O. Balci, Investigation of the effect of raising and finishing process on the physical performance of 3-thread fleece fabric, TEKSTIL VeKonfeksiyon. 32 (2021) 183–192, https://doi.org/10.32710/tekstilvekonfeksiyon.868761.

[9] M.M.U. Hoque, Md.A. Rassel, Impact of machine parameters on knit fabric GSM and shrinkage, European J. Eng. Res. Sci. 4 (2019) 89–92, https://doi.org/10.24018/ejers.2019.4.9.1497.

[10] R. Mishra, H. Jamshaid, S.A. Basra, G. Jiang, Z. Gao, P. Ma, M. Petru, A. Raza, M. Muller, Effect of stitch characteristics on flammability and thermo-physiological comfort properties of knitted fabrics, Fibers Polym. 21 (2020) 2652–2663, https://doi.org/10.1007/s12221-020-1381-8.

[11] A. Assefa, N. Govindan, Physical properties of single Jersey derivative knitted cotton fabric with tuck and miss stitches, J. Eng. Fiber Fabr 15 (2020), https://doi.org/10.1177/1558925020928532.

[12] Z. Deŀirmenci, N. Çelik, An investigation on the influence of laundering on the dimensional stability of the denim-like knitted fabrics, Tekstil ve Konfeksiyon 24 (2014) 363–370.

[13] P. Raichurkar, A Study on Spirality of Single Jersey Knitted Fabric, 2015.

[14] D.B. Sitotaw, An investigation on the dependency of bursting strength of knitted fabrics on knit structures, Ind. Eng. Manag. 6 (2017) 3–6, https://doi.org/10.4172/2169-0316.1000221.

[15] Z. Değirmenci, E. Çoruh, The influences of loop length and raw material on bursting strength air permeability and physical characteristics of single Jersey knitted fabrics, J. Eng. Fiber Fabr 12 (2017) 43–49, https://doi.org/10.1177/155892501701200105.

[16] S. Uyanik, Z. Degirmenci, M. Topalbekiroglu, F. Geyik, Examining the relation between the number and location of tuck stitches and bursting strength in circular knitted fabrics, Fibres Text. East. Eur. 24 (2016) 114–119, https://doi.org/10.5604/12303666.1170266.

[17] A. Sayam, F. Rabbi, M. Hossain, O. Faruque, N. Ahmed, S. Alimuzzaman, F. Ahmed, R. Islam, A.N.M.M. Rahman, Influence of denting order on quality and appearance of cotton based plain woven fabric, J. Nat. Fibers 19 (2022) 8923–8936, https://doi.org/10.1080/15440478.2021.1975599.

[18] M. Kalkanci, Investigation into fabric spirality in various knitted fabrics and its effect on efficiency in apparel manufacturing, Fibres Text. East. Eur. 27 (2019) 59–66, https://doi.org/10.5604/01.3001.0012.7509.

[19] J. Tao, R.C. Dhingra, C.K. Chan, M.S. Abbas, Effects of yarn and fabric construction on spirality of cotton single Jersey fabrics, Textil. Res. J. 67 (1997) 57–68, https://doi.org/10.1177/004051759706700112.

[20] V.K. Kothari, G. Singh, K. Roy, R. Varshney, Spirality of cotton plain knitted fabrics with respect to variation in yarn and machine parameters, Indian J. Fibre Text. Res. 36 (2011) 227–233.

[21] Z. Değirmenci, E. Çoruh, Comparison of the performance and physical properties of plain, pique, double-pique and fleeced knitted fabrics, Tekstil ve Konfeksiyon 26 (2016) 159–165.

[22] L. Rahman, M. Mosharof Hossain, M. Lutfor Rahman, T. Refat Tumpa, M. Kamal Uddin, M. Al-Amin Sarkar, M. Hedayet Hussain, A study on the effect of weft knitted structures and stitch length on the pilling behavior of weft knitted fabrics A study on the effect of weft knitted structures and stitch length on the pilling behavior of weft knitted fabrics view project A study on t, Int. Res. J. Eng. Technol. 7 (2020) 3394–3400.

[23] A. Asif, M. Rahman, F.I. Farha, Effect of knitted structure on the properties of knitted fabric, Int. J. Sci. Res. (IJSR) ISSN (Online Index Copernicus Value Impact Factor 14 (2013) 2319–7064.

[24] S. Uyanik, M. Topalbekiroglu, The effect of knit structures with tuck stitches on fabric properties and pilling resistance, J. Textil. Inst. 108 (2017) 1584–1589, https://doi.org/10.1080/00405000.2016.1269394.