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Development and Investigation of Hybrid Knitted Structures for Sensorial Comfort Properties. Part I - Tuck Stitches

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ABSTRACT
Sensorial evaluation plays an important role in the identification of materials in addition to technical specifications for the wearer. The current study focuses on the development of different hybrid knitted structures with different percentages of knit stitches and tuck. Hundred percent cotton was used to develop unique structures on the 4-cam track single jersey knitting machine. A total of 15 hybrid weft knitted structures are developed with different combinations of knit and tuck stitch percentages. The effects of different amount of knit and tuck stitches on physical parameters, e.g. area density, stitch density, and thickness, were characterized. Sensorial comfort, e.g. resilience, softness, smoothness, drape, and wrinkle recovery rate, were evaluated with the standard test method. After testing and data analysis, it was concluded that percentages of stitch types have a significant effect on the physical parameters and sensorial comfort properties of the fabrics.

摘要
除了佩戴者的技术规范外，感官评估在材料识别方面也发挥着重要作用. 目前的研究重点是开发具有不同针织针脚和褶裥百分比的不同混合针织结构. 100% 纯棉被用于在 4 针道单面针织机上开发独特的结构. 共开发了15种混合纬编结构，具有不同的编织和褶裥百分比组合. 表征了不同编织量和收褶量对物理参数（如面积密度、针脚密度和厚度）的影响. 使用标准测试方法评估感官舒适度，如弹性、柔软度、光滑度、悬垂性和皱纹恢复率. 经过测试和数据分析，得出的结论是，针脚类型的百分比对织物的物理参数和感官舒适性能有显著影响.

KEYWORDS
Knitting; single jersey; sensorial comfort; resilience; softness; smoothness; drape; wrinkle recovery; cotton

关键词
针织; 单人球衣; 感官舒适; 恢复力; 柔软; 平滑度; 德雷普; 皱纹恢复; 棉

Introduction

Textiles differ from each other with their technical structures (Zhang and Ma 2018) in that they must have sufficient strength (SENGUPTA 2022) and performance characteristics, and at the same time, they must be flexible, elastic, easy to pleat and shape (Zulifqar, Hua, and Hu 2018), and comfortable in aesthetic and sensorial aspects (Saeed et al. 2021). Comfort is influenced by a variety of psychological, physiological, and physical factors between a human being and the external environment (Dalbași and Kayseri 2021). The main purpose of clothing is to provide comfort and protect the wearer from cold or warm conditions, rain, snow, and wind (Ghaffari, Yousefzadeh, and Mousazadegan 2019), and that it is important for the human body to maintain a temperature around 37 ◦C between fabric and body surface (Wan, Wang, and 2018). Clothing has now been engineered with greater functionality to maximize comfort (Pakdel et al. 2019) and facilitate the maintenance of thermal homeostasis during

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various physical and environmental variables (Lou, Chen, and Fan 2021). Knitted fabrics are widely used in sportswear, summer clothes, underwear, and child clothes (Khalil et al. 2021) due to their excellent stretch and recovery, porosity, and air permeability (Vasile et al. 2019). Also, knitted fabrics, especially weft knitted fabrics, are easier to be produced and have less cost compared to woven fabrics (Kamal et al. 2020).

The properties of a knitted fabric are largely determined by the interdependence of each stitch with its neighbors on either side and above and below it (Bouagga, Harizi, and Sakli 2021). The width of the fabric is influenced by the structure of the knitted fabric (knit, tuck, and miss loops) and the machine parameters (gauge, yarn feeding tension) (Assefa and Govindan 2020). Tuck stitch have important influence on fabric properties (Uyanik and Topalbekiroglu 2017). It increases the weight, thickness, and width and makes the fabric more porous than the other fabrics (Bouagga, Harizi, and Sakli 2022). Structures with tuck stitches are wider than a normal knit structure (Mishra et al. 2021). The loop shape at the tuck stitch is distorted and has a wider base as the side wales are not pulled together (Bouagga, Harizi, and Sakli 2021). Several researchers have analyzed the effects of knitted structures on the width of the fabric. They have found that knitted structures have a major influence on the width of the fabric (Arumugam et al. 2017; Bouagga, Harizi, and Sakli 2021; Farha et al. 2019). The position and sequence of tuck stitches plays vital role in properties of fabric (Uyanik et al. 2016). When the location of tuck stitches is not in the zig zag form, the fabric does not pick up very much and the tightness of structure is very low; thus, the resistance of the fabric to air pressure force decreases (Kane, Patil, and Sudhakar 2007). Knitting fabric structures offer better thermo-physiological comfort, are soft to the touch, and are lightweight (Arumugam et al. 2018). Knitted construction parameters, such as yarn linear density, stitch density, and fabric structure, have great influences on fabric porosity values, which has an impact on the fabric air permeability, wicking, and moisture transmission characteristics (Senthil Kumar, Kumar, and Rachel 2020; Yang et al. 2019). The increase in fabric porosity consequently increases the air permeability of the fabric and the wetting time with a decrease in the liquid moisture absorption rate, the spread speed, and the maximum wetted radius of the fabric (Karthikeyan et al. 2017). Knitted fabric parameters and properties vary with changes in structures. If the fabric thickness is increased, thermal resistance also increases, which means thicker knitted fabric gives a warmer sense (Subburaayasaran et al. 2022). Different knitted structures have different comfort properties (Yang et al. 2021). The results of different studies showed that the addition of tuck stitches to the knit stitches improved fabric properties e.g., abrasion resistance, air permeability, water absorbency, thermal insulations, compression, bending shear, tensile properties, and handle values (Ayodele et al. 2021). Double jersey structures have high thermal insulation, which may be preferred for winter garments (Erdumlu and Saricam 2017). Single jersey structures are preferred for sports or summer garments due to their better moisture management properties (Kumar, Kumar, and Rachel 2020). The sensory feeling is affected by structure parameters that affect process parameters on textile tactile quality, such as fiber type, yarn properties, fabric structure, finishing treatments, and clothing conditions (Akgül, Aydoğan, and Sinanoğlu 2021).

Although the comfort properties have been studied by different researchers, there is hardly any research work on the sensorial characteristics of cotton hybrid (combinations of different structures in courses are wales) knitted fabrics concerning knit and tuck percentages. Hence, in this study, different knitted structures with different knit stitches and tucks were developed to analyze the resilience, softness, smoothness, drape, and wrinkle recovery properties of knitted fabric.

Materials and methods

Materials

In this study, 100% cotton yarn 29.5 tex was used to develop knitted fabric samples. Cotton fiber properties, e.g., fiber length, uniformity index, fiber strength, elongation was 27.86 mm, 83.6%, 33.2cN/tex and 5.8%, respectively. The yarn properties e.g., breaking force, tenacity, elongation, twist, lea strength, moisture regain, and CLSP (Count Lea Strength in Pounds), were 245cN, 7.6cN/tex, 5.3%, 7 twist per cm, 542 N, 8.5%, and 3194, respectively.

Fabric developments

A circular weft knitting single jersey machine (FUKUHARA, Japan, 1992 FXC–3S) with 4 tracks, a diameter of 30 inches, 20E gauge, 90 feeders, and 1884 needles was used to develop knitted samples. Different sequences of cams (knit and tuck cams) on the circumference of the machine cylinder were installed to develop 15 knitted fabric structures.

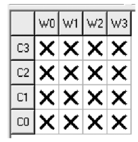
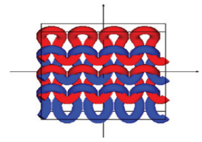
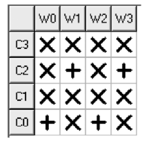
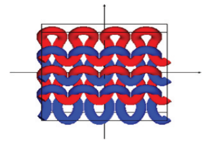
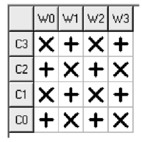
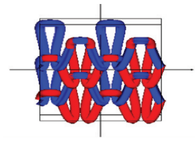
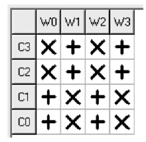
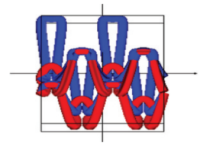
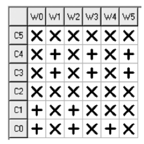
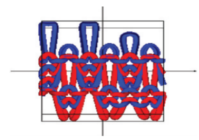
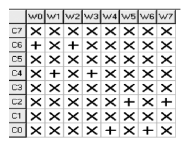
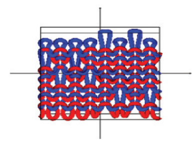
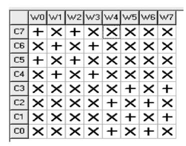
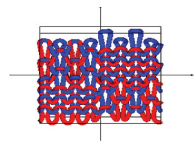
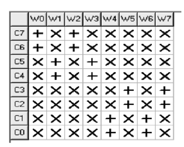
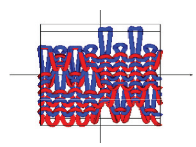
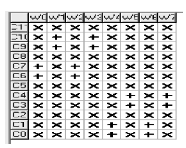
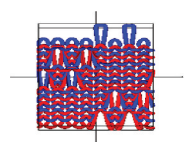
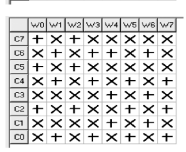
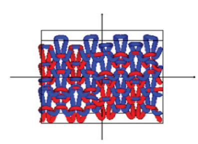
The first 5 samples were single jersey S0 (all knitting cams), single pique S1 (1^{st} and 3rd course with all knit cams and 2^{nd} and 4^{th} course with alternate tuck and knit cams), cross tuck S2 (alternate single tuck and knit cams in all courses), polo pique S3 (alternate double tuck and knit cams in all courses), and double pique S4 (1^{st} and 4^{th} course with all knit cams and 2^{nd} & 3^{rd} and 5^{th} & 6^{th} cams with 2 alternate double tuck and knit cams). The rest of the 10 samples were developed with combinations of 1^{st} five structures (S0, S1, S2, S3, S4) in the form of two small squares (24 courses and 20 wales) of different fabric structures in an alternate way as shown in Table 1. Combinations of knitting designs were single jersey and single pique (S0.S1), single jersey and cross tuck (S0.S2), single jersey and polo pique (S0.S3), single jersey and double pique (S0.S4), single pique and cross tuck (S1.S2), single pique and polo pique (S1.S3), single pique and double pique (S1.S4), cross tuck and polo pique (S2.S3), cross tuck and double pique (S2.S4), and polo pique and double pique (S3.S4). Cams tracks were divided into two sets with alternate knitting structures; first set of 20 needle passes through first two cam tracks, which produce twenty wales of first structure, and the next 20 needles pass through the rest of the second cam tracks, which produces twenty wales of second structure and vice versa. In this way, alternate fabric structures were produced in width-wise directions. The machine feeders were divided into two sets of 24 feeders. The first set of 24 feeders developed the first structure, and the second set of 24 feeders produced the second structure. This staging sequence produces an alternate structure of 24 courses in length. These combinations of needle and feeder on the machine produce small squares in the fabric in both length and width direction. The design of the experiment with knit and tuck stitch percentages and knitting designs are given in Table 1.

Fabric testing

After development, all knitted fabric samples were conditioned (R.H.65 ± 2%, Temperature 20 ± 2°C) according to standard ASTM D 1776. The area density of all samples and fabric thickness were measured according to standard Method ASTM D– 3776 and Standard ASTM D–1777, respectively. Fabric densities (courses/cm^{-1} and wales/cm^{-1}) were calculated according to ASTM D 8007.

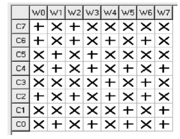
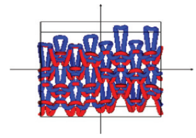
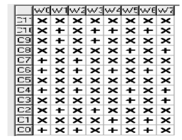
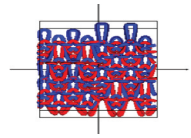
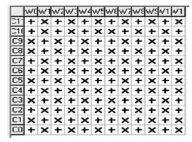
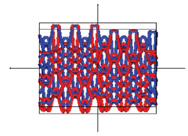
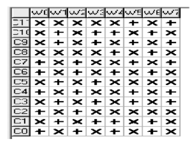
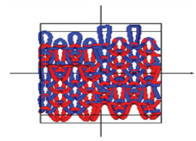
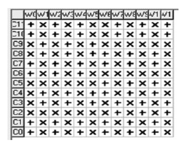
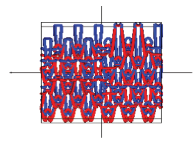
The phabrOmeter® was used to measure the sensorial comfort of developed knitted fabric samples instrument and standard test method of AATCC TM–202 was followed. The sensorial comfort of knitted fabrics was determined by using phabrOmeter instrument which was developed by Prof. Dr. Ning Pan in the USA. This device can measure all skin-related properties except the moisture management. This machine works on the principle of nozzle extraction to determine fabric handle properties. Five samples of 113 ± 2 mm diameter from different positions of fabric sheet were cut for placement in the testing machine. The thickness and weight of these samples are determined according to standard test methods to use in the software of phabrOmeter. Testing machine distorted fabric samples with low-stress mechanical force (LSMF) like shear, tensile, compression, friction, and bending. During the test, the circular piece of fabric is placed in the plates by keeping the face side of fabric toward top plate for all samples. Nozzle passed through pressed sample and software determine the values of different factors. Sensorial comfort such as resilience (how easy you can wrinkle the fabric with hand), softness (compressibility judged by squeezing the fabric with hand), smoothness (resistance when you slide hand across the sample), drape (multi-curvature deformability of fabrics), and wrinkle recovery rate (how a fabric sample can recover from wrinkle deformation) can

Table 1. Design of experiments with knit, tuck stitch percentages and knitting structures.

Sr. no.	Sample code	Knit structure	Knit stitch %	Tuck stitch %	Needle Diagrams	Knitting structure
1	S0	Single-Jersey	100	0		
2	S1	Single Pique	75	25		
3	S2	Cross Tuck	50	50		
4	S3	Polo Pique	50	50		
5	S4	Double Pique	66.66	33.33		
6	S0.S1	Single Jersey and Single Pique	87.5	12.5		
7	S0.S2	Single Jersey and Cross Tuck	75	25		
8	S0.S3	Single Jersey and Polo Pique	75	25		
9	S0.S4	Single Jersey and Double Pique	83.33	16.67		
10	S1.S2	Single Pique and Cross Tuck	62.5	37.5		

(*Continued*)

Table 1. (Continued).

Sr. no.	Sample code	Knit structure	Knit stitch %	Tuck stitch %	Needle Diagrams	Knitting structure
11	S1.S3	Single Pique and Polo Pique	62.5	37.5		
12	S1.S4	Single Pique and Double Pique	70.83	29.17		
13	S2.S3	Cross Tuck and Polo Pique	50	50		
14	S2.S4	Cross Tuck and Double Pique	58.33	41.66		
15	S3.S4	Polo Pique and Double Pique	58.33	41.67		

be measured with this instrument. These parameters allow the quantitative comparison the sensory properties of fabrics.

Results and discussion

The results of physical parameters with sensorial comfort, e.g., resilience, softness, smoothness, drape, and wrinkle recovery rate are given in Table 2. The sensorial comfort results were analyzed using different statistical analyses.

It was observed that thickness, stitch density, and area density changes with the change in tuck stitch percentage and fabric structure as shown in Figure 1. Sample S0 (single jersey) with all knit stitches showed highest stitch density and lowest thickness due to the even distribution of stitches throughout the fabric structure (Değirmenci and Çoruh 2017). Knit structure with two consecutive tuck loops (S3 and S4) showed higher stitch densities as compared to single tuck loops (S1, S2) due to the overlap of three heads of loops during knock over of needle in a loop formation process. Two tuck loops with one knit loop in sample S4 showed high stitch densities as compared to two tuck loops in S3. The same trend of thickness, stitch density, and area density was observed in the developed hybrid knitted fabric structures with the combinations of S0, S1, S2, S3, and S4. Physical parameters, e.g., thickness, stitch density, and area density can be predicted with tuck stitches percentage by using equations given in Table 3.

The probability plot in Figure 2 showed the normal distribution of that the data P-value and Anderson-Darling (AD) density and thickness are statistically significant. Moreover, the P-values of tuck % and area density are not statistically significant due to their high values.

Table 2. Sensorial results of developed knitted fabric structures.

Sr. no.	Sample code	Area density (g/m^2)	Stitch density (cm^{-2})	Thickness (mm)	Resilience	Softness	Smoothness	Drape	Wrinkle Recover Rate (%)
1	S0	214.03	264.28	0.627	28.1	79.18	59	7.53	58.46
2	S1	224.33	122.76	0.813	41.57	74.29	65.12	16.18	38.3
3	S2	227.13	127.57	0.833	37.69	79.21	64.77	12.71	30.59
4	S3	232.47	132.99	0.916	36.21	79.65	64.26	11.71	28.98
5	S4	241.73	159.03	0.962	31.61	82.11	63.95	8.38	17.16
6	S0.S1	222.33	162.75	0.753	30.27	78.06	60.49	8.69	62.6
7	S0.S2	223.50	179.34	0.767	29.51	78.17	60.18	8.57	58.47
8	S0.S3	227.66	187.40	0.811	29.55	78.7	59.22	8.36	55.41
9	S0.S4	229.60	195.30	0.913	28.99	79	59.02	8.22	54.86
10	S1.S2	225.13	128.19	0.817	36.49	77.7	63.8	12.73	51.17
11	S1.S3	233.90	130.51	0.920	36.24	78.02	63.64	12.33	38.76
12	S1.S4	237.13	145.08	0.926	35.72	79.36	62.22	11.8	27.32
13	S2.S3	234.33	130.67	0.923	37.39	77.84	64.4	11.79	34.17
14	S2.S4	238.66	145.08	0.954	35.88	78.97	64.05	11.48	32.78
15	S3.S4	240.17	147.72	0.960	35.58	80.03	63.44	11.23	29.18

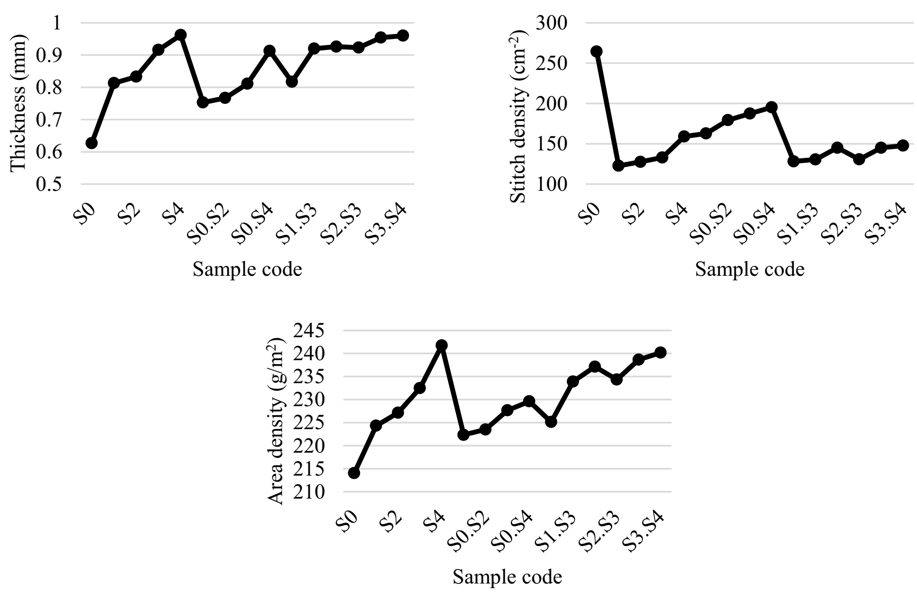


Figure 1. Thickness, stitch density, and area density of developed knitted fabric samples.

Table 3. Prediction equations of physical parameters of developed knitted fabric samples.

S. No.	Equation	R^2
1	Thickness = −0.0003(Area Density)^2 + 0.1482 Area Density − 17.482	0.9635
2	Thickness = −0.0001(Tuck %)^2 + 0.0128 Tuck % + 0.6325	0.6123
3	Thickness = −2E−05(Stitch Density)^2 + 0.0055 Stitch Density + 0.49	0.4924
4	Stitch Density = 0.0533(Tuck %)^2 − 5.0312Tuck % + 252.39	0.757
5	Stitch Density = 0.3201 (Area Density)^2 − 149.25 Area Density + 17532	0.5934
6	Area Density = −0.0118 (Tuck %)^2 + 0.9944 Tuck % + 212.82	0.5394

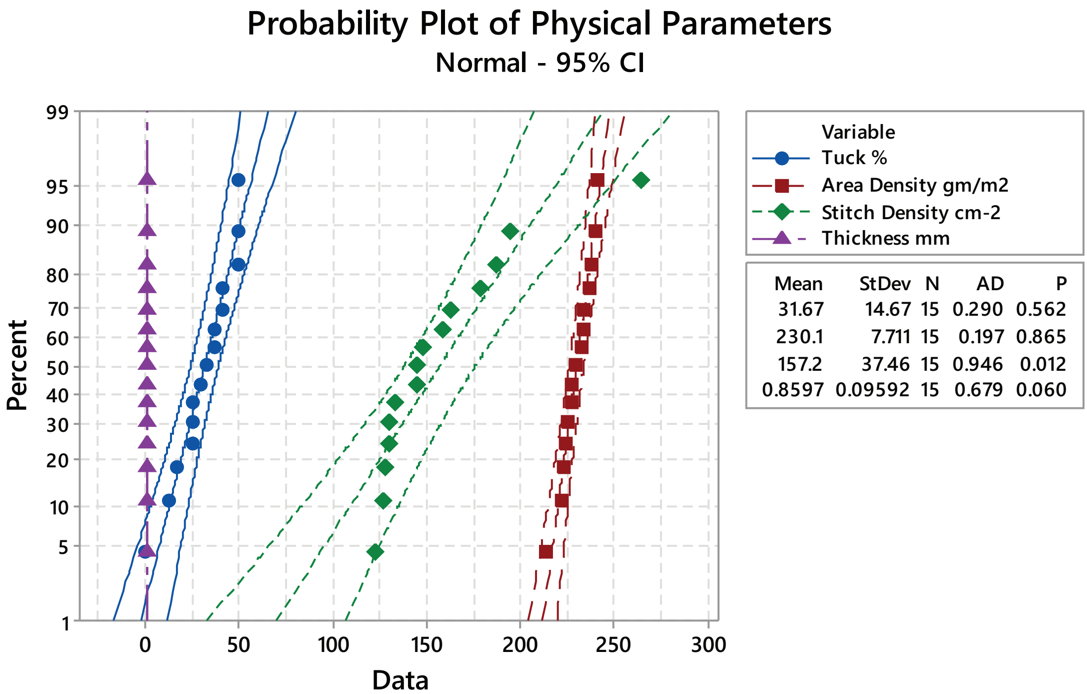


Figure 2. Probability plot of the physical parameters of knitted fabrics.

Resilience

To increase the resilience of knitted fabric, and therefore their capacity to absorb energy, a relaxed stretchable loop structure is required (ARAUJO, Fangueiro R, and Hong 2004). The resilience results of all samples in Figure 3 showed that knitted structures with all knit loops (S0) showed the lowest resilience compared to structures with tuck loops. It was observed that single tuck loops increase resilience compared to consecutive two tuck loops in the fabric. This recovery of the original shape of the loops after the load was due to the lower densities of these samples. Samples with double tuck showed poor resilience due to their poor attainment of a stagging sequence of three heads of the loop on each other (Wadekar et al. 2021) after the removal of external force. A similar trend of resilience was observed in hybrid knitted structure samples. The attainment of original shape after the removal of external force was due to the geometry of overlapping of loop heads with the previous loop. Lower resilience was observed in single jersey and single jersey hybrid knitted structures due to poor densities of fabrics. The resilience score decreased with an increase in thickness, area density, and stitch density of the fabrics due to overlapping of tuck stitches.

Smoothness

The smoothness of fabric structures with single tuck loops (S1 and S2) was higher as compared to double tuck loops (S3 and S4) as shown in Figure 3. Two tuck loops create roughness on the surface of fabrics due to the overlapping yarn making fabric surface bumpy (Amin et al. 2021). Hybrid knitted fabric samples showed the lowest smoothness due to the presence of different structures in each box (one box contain one repeat of knitted design) of fabric. Thickness, stitch density, and area density have a significant impact on the smoothness of the fabrics. In single and hybrid structures, smoothness increases with a decrease in thickness, stitch density, and area density and vice versa due to more fibers and loops availability within the fabric cross-section, which causes more compactness of structure with less waviness of the fabric, resulting in a reduction in smoothness. Smoothness of fabrics with similar composition decreases when their mass per unit area increases (Vasile et al. 2019).

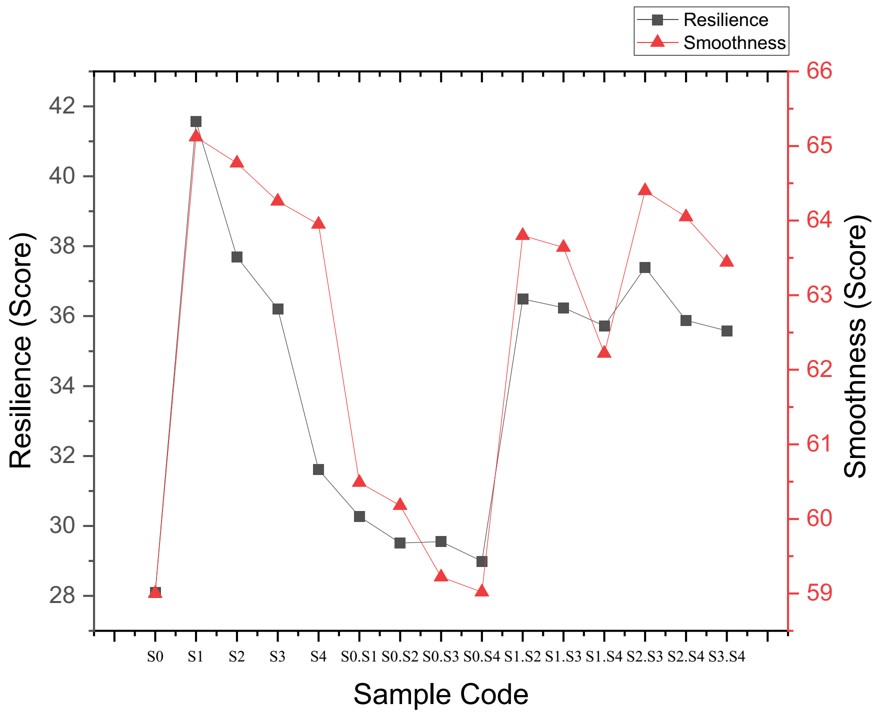


Figure 3. Resilience and smoothness results of knitted fabric samples.

Softness

Mass per unit area has significant influence on the softness of knitted fabric (Vasile et al. 2019). It was observed in the developed samples that softness increases with an increase in thickness, stitch density, and area density of fabric as shown in Figure 4. Softness scores of single jersey (S0) and single pique (S1) was 79.18 and 74.29, respectively. Stagging of three loop heads in double tuck loop samples (S3 and S4) showed the highest softness due to an increase in fiber contents and stitch density with compressibility. The softness score changes with the change in the knit structure in the fabrics. The double pique (S4) and double pique hybrid structures showed the highest softness due to the waviness that occurred by the interloping sequence of the tuck stitches with knit stitches (Jamshaid, Awais, and Mishra 2017), as shown in Figure 4.

Drape coefficient

Change in tuck stitch percentage and position of tuck stitches in knitted fabric changed the thickness and weight, which are associated with drape and fullness of the piece of clothing (Choi and Ashdown 2000). Single jersey fabric showed lowest drape due to highest stitch density and lowest thickness and area density as compared to samples made with tuck stitches as shown in Figure 5. Double pique(S4) sample showed lowest score of drape due to consecutive 2 tuck loops in the single course. Two consecutive combine tuck loops make the fabric fluffier as compared to other knitted designs which causes increase in the drape of fabric. The single jersey showed the lowest drapeability due to the uniform distribution of loops in the fabric with low area density and thickness.

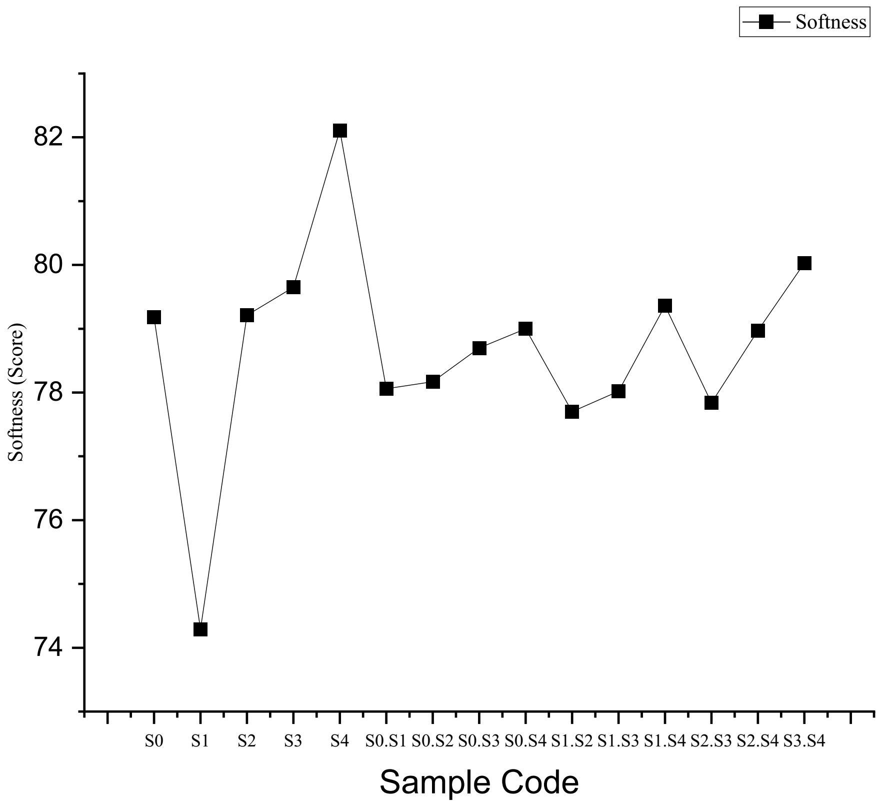


Figure 4. Softness score of developed knitted samples.

Wrinkle recovery rate

When the fabric compactness increases the wrinkle resistance increases, the fabric's stiffer wrinkle resistance decreases and wrinkle recovery becomes more difficult (Mansoor et al. 2018). It was observed from the results that a single jersey hybrid knitted structures showed the highest wrinkle recovery rate as shown in Figure 5. Double piques(S4) structures showed lowest recovery rate from wrinkles due to 2 consecutive tuck stitches with one knit course. Wrinkle recovery rate reduced with an increase in tuck stitches percentage in the fabric structure. Two consecutive tuck stitches in fabric structures S3 and S4 showed the lowest wrinkle recovery rate due to higher thickness, stitch density, and area density (Assefa and Govindan 2020) as compared to single tuck loops (S1 and S2) in the fabrics. A similar trend was observed in hybrid structures; however, wrinkle recovery rate was improved when single jersey (S0) structures were added with tuck stitch structures in hybrid knitted fabrics.

Optimizations of sensorial comfort parameters

After data analysis, a significant relation was found between different sensorial comfort properties. The prediction equations are given in Table 4. With the help of these equations, different output variables can be calculated.

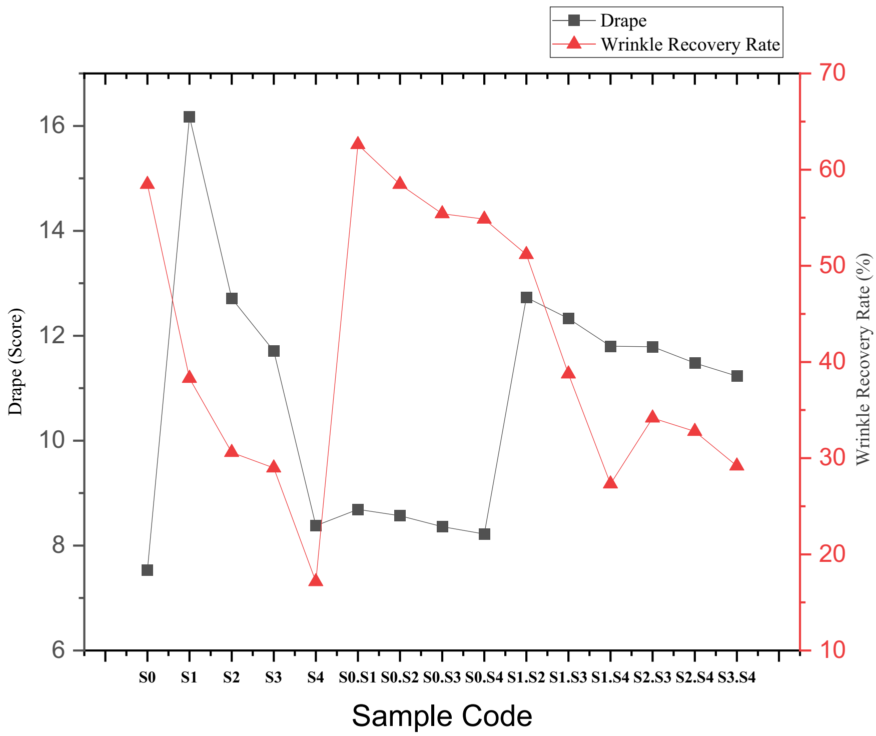


Figure 5. Drape and wrinkle recovery rate of samples.

Table 4. Prediction equations of sensorial comfort properties.

S. No.	Equation	R^2
1	Softness = −0.0728 (Resilience)^2 + 4.7692 Resilience + 1.7997	0.6317
2	Smoothness = −0.0329 (Resilience)^2 + 2.7434 Resilience + 7.7224	0.8652
3	Drape = 0.0229 (Resilience)^2 − 0.9761 Resilience + 17.105	0.9692
4	Wrinkle Recover Rate (%) = 0.3826 (Resilience)^2 − 28.134 Resilience + 549.79	0.5242
5	Smoothness = 0.1738(Softness)^2 − 27.323 Softness + 1135.7	0.1715
6	Drape = 0.1147 (Softness)^2 − 18.777 Softness + 777.84	0.4048
7	Wrinkle Recover Rate (%) = −1.3497 (Softness)^2 + 207.52 Softness − 7927.3	0.3865
8	Drape = 0.1209 (Smoothness)^2 − 14.101 Smoothness + 419.34	0.6788
9	Wrinkle Recover Rate (%) = 0.616 (Smoothness)^2 − 81.115 Smoothness + 2701.7	0.612
10	Wrinkle Recover Rate (%) = 0.7446 (Drape)^2 − 19.458 Drape + 160.43	0.325

In the Minitab® fit regression model, it was observed that physical parameters, e.g., area density, stitch density, tuck stitch %, and thickness of knitted samples have significant effect on the sensorial comfort properties, e.g., resilience, softness, smoothness, drape, and wrinkle recovery rate. Regression equations are given in Table 5. The results obtained in this research work indicated that fabric physical parameters indicated a positive correlation with sensorial comfort properties of developed samples. The coefficient of determination (R^2) was 0.71 and the *P* value of 0.000 was less than 0.05, hence the model was significant. The relationship between resilience and stitch density was therefore statistically significant and can be used to study the effect of stitch density on the resilience of knitted fabrics. Softness, smoothness, drape, and wrinkle recovery rate also showed statistically significant relationship (P-value is less than 0.005) with area density, stitch density, tuck stitch %, and thickness.

Table 5. Regression equations of sensorial comfort properties w.r.t. physical properties.

S. No.	Equation	P-value	R^2
1	Resilience = 48.35 − 0.0909 Stitch Density	0.000	0.71
2	Softness = 36.4 + 0.0585 Tuck Stitch % + 0.1449 GSM + 0.0448 Stitch Density	0.008	0.65
3	Smoothness = 70.58 − 0.05137 Stitch Density	0.000	0.72
4	Drape = 43.7 − 0.1010 GSM − 0.0617 Stitch Density	0.009	0.70
5	Wrinkle Recover Rate (%) = 305.8 − 0.314 Tuck Stitch % − 1.107 GSM	0.003	0.70

The probability plot for the sensorial comfort properties data showed that the data points for both distributions fall close to the fitted normal line and within the confidence interval. P-values also indicate that data distribution is statistically significant; furthermore, the Anderson-Darling (AD) values are also small suggesting normal distribution fits, as shown in Figure 6. The basis of the P-value and AD-value fitted line can be used as estimated percentiles for sensorial comfort scores.

In residual plot of resilience, softness, smoothness, drape, and wrinkle recovery rate, the histogram, normal probability plot, residuals versus fits, residuals versus order, and residuals versus the variables are given in Figure 7. It can be seen from the histogram of standardized residuals that standardized residual of regression and experimental values were approximately normal distributed in all variables. In the normal probability plot of the standardized residuals, where most of the scatter points of the standardized residuals were distributed on or close to the diagonal line, so the residuals were also normally distributed. The scatter plot of the standardized residuals in Figure 7, in which the points were evenly distributed with no obvious regular variation, and so the variance of the residuals was homogeneous.

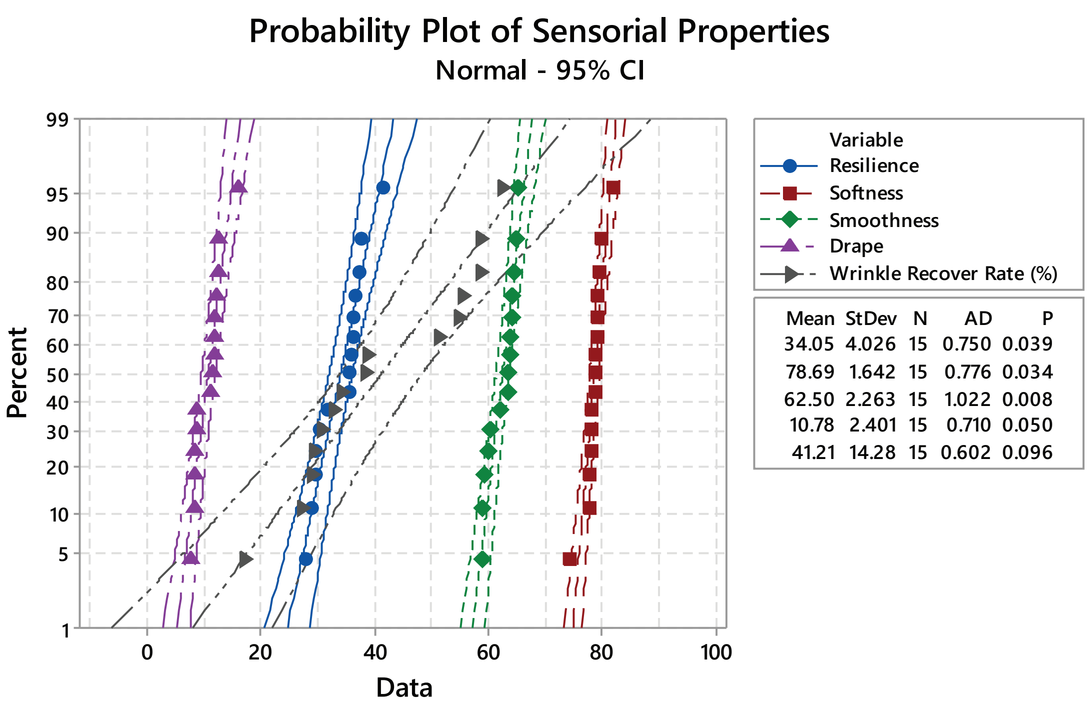


Figure 6. Probability plot of the properties of sensorial comfort.

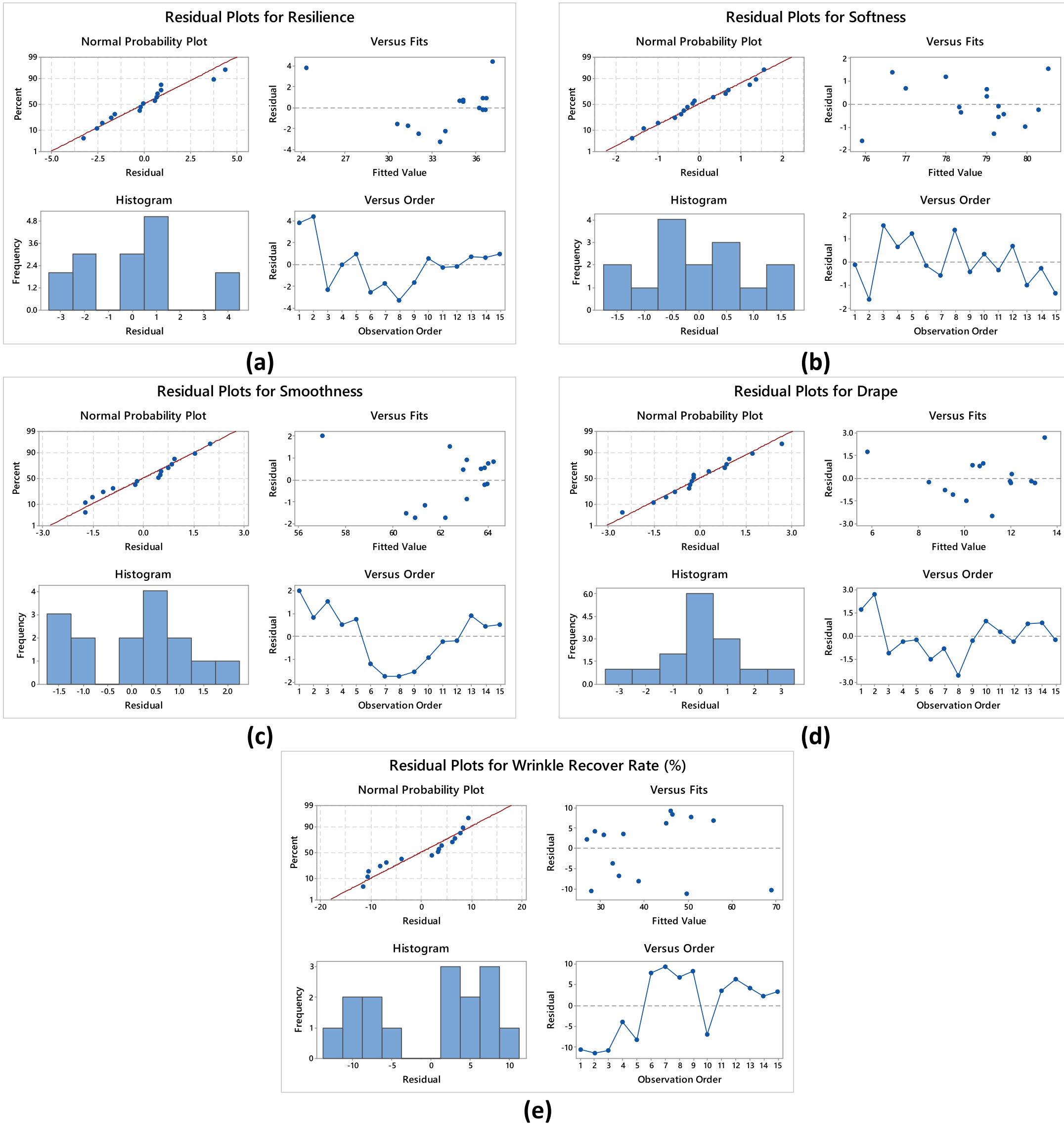


Figure 7. Residual plot of sensorial comfort properties.

Conclusion

It was concluded that hybrid structures have different physical as well as comfort properties. Combinations of knit and tuck stitch percentages influence the thickness, area density, and stitch density. Knitted structures with two consecutive tuck loops showed the highest area, and stitch densities as compared to single tuck loops. Thickness increased with the addition of tuck loops in the fabric structures. It was concluded that sensorial comfort properties, e.g., resilience, softness, smoothness, drape, and wrinkle recovery correlate with physical parameters and used stitch types.

The knitted structures with all knit loops showed the lowest resilience compared to the structures with tuck loops. It was observed from the results that single tuck loops increase resilience compared to consecutive two tuck loops in the fabric. The smoothness of the fabric structure with a single tuck loop was improved as compared to the double tuck loops while single jersey hybrid knitted samples showed the lowest smoothness. Thickness, stitch density, and area density have a significant impact on the smoothness of the fabrics. It was concluded that softness increases with an increase in thickness, stitch density, and area density of the fabric. The softness score changes with the change in the knit structure of the fabrics. Double pique and double pique hybrid structures showed the highest softness. Drape coefficient of the samples also changed with change in tuck stitch percentage and physical parameters. It was concluded that all knit stitches with tuck stitch structures showed the highest wrinkle recovery rate. Wrinkle recovery reduced with an increase in tuck stitches in the fabrics. Two consecutive tuck stitches showed the lowest recovery from the wrinkles.

Highlights

Some salient features of this research work that is aimed to submit in this Journal of Natural Fibers are:

(1) This work mainly focusses on the development of some novel knitted structures with the name of hybrid knitted fabric structures.
(2) Fabric physical properties of these hybrid structures was characterized.
(3) One of the main objectives of this research work was to study the tuck stitches percentage on physical properties of different knitted structures.
(4) Sensorial comfort properties were also characterized to understand the variations in the fabric feel/comfort to decide their end applications

Disclosure statement

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Ethical approval

This submitted article is following the ethical guidelines of research and publication. All the data is accessible by the authors and submitted here with their agreement.

References

Akgül, E., K. Aydoğan, and E. Sinanoğlu. 2021. Investigation of different denim fabrics with fabric touch tester and sensory evaluation. *Journal of Natural Fibers* 19 (13):5551–5565. doi:10.1080/15440478.2021.1881687.

Amin, M., R. Mishra, A. Mahmud, and F. R. Anannya. 2021. Structural impact on some common physical properties of single jersey weft knit fabric. *AATCC Journal of Research* 8 (4):36–46. doi:10.14504/ajr.8.4.6.

ARAUJO, D., M. Fangueiro R, and H. Hong. 2004. Modelling and simulation of the mechanical behaviour of weft-knitted fabrics for technical applications. *AUTEX Research Journal* 4 (2):72–80.

Arumugam, V., R. Mishra, M. Jiri, L. Davies, and S. Slater. 2018. Thermal and water vapor transmission through porous warp knitted 3D spacer fabrics for car upholstery applications. *The Journal of the Textile Institute* 109 (3):345–57. doi:10.1080/00405000.2017.1347023.

Arumugam, V., R. Mishra, M. Jiri, and J. Salacova. 2017. Investigation on thermo-physiological and compression characteristics of weft-knitted 3D spacer fabrics. *The Journal of the Textile Institute* 108 (7):1–11. doi:10.1080/00405000.2016.1220035.

Assefa, A., and N. Govindan. 2020. Physical properties of single jersey derivative knitted cotton fabric with tuck and miss stitches. *Journal of Engineered Fibers and Fabrics* 15:155892502092853. doi:10.1177/1558925020928532.

Ayodele, E., S. A. R. Zaidi, J. Scott, Z. Zhang, M. Hafeez, and D. McLernon. 2021. The effect of miss and tuck stitches on a weft knit strain sensor. *Sensors* 21 (2):358. doi:10.3390/s21020358.

Bouagga, T., T. Harizi, and F. Sakli. 2021. The effect of tuck stitch on the properties of weft knitted fabric. *Journal of Natural Fibers* 19 (15):1–12. doi:10.1080/15440478.2021.1993415.

Bouagga, T., T. Harizi, and F. Sakli. 2022. The effect of tuck stitch on the properties of weft knitted fabric. *Journal of Natural Fibers* 19 (15):9874–85. doi:10.1080/15440478.2021.1993415.

Choi, M.-S., and S. P. Ashdown. 2000. Effect of changes in knit structure and density on the mechanical and hand properties of weft-knitted fabrics for outerwear. *Textile Research Journal* 70 (12):1033–45. doi:10.1177/004051750007001201.

Dalbaşi, E. S., and G. Ö. Kayseri. 2021. A research on the comfort properties of linen fabrics subjected to various finishing treatments. *Journal of Natural Fibers* 18 (6):909–22.

Değirmenci, Z., and E. Çoruh. 2017. The influences of loop length and raw material on bursting strength air permeability and physical characteristics of single Jersey knitted fabrics. *Journal of Engineered Fibers and Fabrics* 12 (1):155892501701200. doi:10.1177/155892501701200105.

Erdumlu, N., and C. Saricam. 2017. Investigating the effect of some fabric parameters on the thermal comfort properties of flat knitted acrylic fabrics for winter wear. *Textile Research Journal* 87 (11):1349–59. doi:10.1177/0040517516652347.

Farha, F. I., S. A. Smriti, M. A. A. H. S. Sarker, and F. Xu. 2019. Fibrous impact on several primary characteristics of three-thread fleece fabric. *AATCC Journal of Research* 6 (5):30–38. doi:10.14504/ajr.6.5.5.

Ghaffari, S., M. Yousefzadeh, and F. Mousazadegan. 2019. Investigation of thermal comfort in nanofibrous three-layer fabric for cold weather protective clothing. *Polymer Engineering & Science* 59 (10):2032–40. doi:10.1002/pen.25203.

Jamshaid, H., H. Awais, and R. Mishra. 2017. The mechanical, comfort & UV resistance properties on interlock derivatives. In *Novelties in Fibrous Material Science*, ed. Jiří Militký, 4th ed., 457–476. Technická univerzita v Liberci, Studentská 1402/2, Liberec. ISBN978-80-7494-390-4.

Kamal, M. S., E. Mahmoud, A. Hassabo, and M. M. Eid. 2020. Effect of some construction factors of bi-layer knitted fabrics produced for sports wear on resisting ultraviolet radiation. *Egyptian Journal of Chemistry* 63 (11):4369–78.

Kane, C. D., U. J. Patil, and P. Sudhakar. 2007. Studies on the influence of knit structure and stitch length on ring and compact yarn single jersey fabric properties. *Textile Research Journal* 77 (8):572–82. doi:10.1177/0040517507078023.

Karthikeyan, G., G. Nalakilli, O. Shanmugasundaram, and C. Prakash. 2017. Moisture management properties of bamboo viscose/tencel single jersey knitted fabrics. *Journal of Natural Fibers* 14 (1):143–52. doi:10.1080/15440478.2016.1187700.

Khalil, A., A. Fouda, P. Těšinová, and S. A. Eldeeb. 2021. Comprehensive assessment of the properties of cotton single Jersey knitted fabrics produced from different lycra States. *AUTEX Research Journal* 21 (1):71–78. doi:10.2478/aut-2020-0020.

Kumar, C., B. S. Kumar, and D. A. Rachel. 2020. Comfort aspects of sportswear base fabrics: A review. *Journal of Emerging Technologies and Innovative Research* 7:1071–76.

Lou, L., K. Chen, and J. Fan. 2021. Advanced materials for personal thermal and moisture management of health care workers wearing PPE. *Materials Science & Engineering: R: Reports* 146:100639. doi:10.1016/j.mser.2021.100639.

Mansoor, T., H. F. Siddique, A. Ali, P. Komarkova, A. Havelka, and Z. Hussain. 2018. Wrinkle free plaited knitted fabrics without pre-heat setting. *The Journal of the Textile Institute* 109 (3):307–11. doi:10.1080/00405000.2017.1342585.

Mishra, R., H. Jamshaid, S. H. S. Yosfani, U. Hussain, M. Nadeem, M. Petru, M. Tichy, and M. Muller. 2021. Thermo physiological comfort of single jersey knitted fabric derivatives. *Fashion and Textiles* 8 (1):1–22. doi:10.1186/s40691-021-00266-5.

Pakdel, E., M. Naebe, L. Sun, and X. Wang. 2019. Advanced functional fibrous materials for enhanced thermoregulating performance. *ACS Applied Materials & Interfaces* 11 (14):13039–57. doi:10.1021/acsami.8b19067.

Saeed, A., K. Iqbal, H. S. Maqsood, and A. Basit. 2021. Thermal and comfort properties of polyester/micro-polyester and cotton/regenerated fibers blended knitted fabrics. *Journal of Natural Fibers* 19 (14):1–11. doi:10.1080/15440478.2021.1982812.

SENGUPTA, S. 2022. Development of jute fabric for Jute-Polyester biocomposite considering structure–property relationship: Jute fabric structure for biocomposite. *Journal of Natural Fibers* 19 (5):1864–78. doi:10.1080/15440478.2020.1788495.

Subburaayasaran, A., S. K. Sampath Kumar, D. Vasanth Kumar, T. Ramachandran, C. Prakash, and H. Vijayakumar. 2022. Comparative studies on thermal comfort properties of eri silk, wool/eri silk, cotton, and micro-denier acrylic double-layered knitted fabrics. *Journal of Natural Fibers* 19 (15):11449–57. doi:10.1080/15440478.2022.2025982.

Uyanik, S., Z. Degirmenci, M. Topalbekiroglu, and F. Geyik. 2016. Examining the relation between the number and location of tuck stitches and bursting strength in circular knitted fabrics. *Fibres & Textiles in Eastern Europe* 24 (1(115)):114–19. 10.5604%2F12303666.1172066.

Uyanik, S., and M. Topalbekiroglu. 2017. The effect of knit structures with tuck stitches on fabric properties and pilling resistance. *The Journal of the Textile Institute* 108 (9):1584–89. doi:10.1080/00405000.2016.1269394.

Vasile, S., A. De Raeve, B. Malengier, and J. Cools. 2019. Effect of biaxial stretch and domestic washing on air permeability of elastic knitted fabrics for sportswear. *Fibers and Polymers* 20 (4):868–75. doi:10.1007/s12221-019-8871-6.

Wadekar, P., C. Amanatides, L. Kapllani, G. Dion, R. Kamien, and D. E. Breen. 2021. Geometric modeling of complex knitting stitches using a bicontinuous surface and its offsets. *Computer Aided Geometric Design* 89:102024. doi:10.1016/j.cagd.2021.102024.

Wan, X., F. Wang. 2018. Numerical analysis of cooling effect of hybrid cooling clothing incorporated with phase change material (PCM) packs and air ventilation fans. *International Journal of Heat and Mass Transfer* 126:636–48. doi:10.1016/j.ijheatmasstransfer.2018.05.155.

Yang, Y., L. Chen, T. Naveed, P. Zhang, and A. Farooq. 2019. Influence of fabric structure and finishing pattern on the thermal and moisture management properties of unidirectional water transport knitted polyester fabrics. *Textile Research Journal* 89 (10):1983–96. doi:10.1177/0040517518783349.

Yang, Y., X. Yu, L. Chen, and P. Zhang. 2021. Effect of knitting structure and yarn composition on thermal comfort properties of bi-layer knitted fabrics. *Textile Research Journal* 91 (1–2):3–17. doi:10.1177/0040517520932557.

Zhang, X., and P. Ma. 2018. Application of knitting structure textiles in medical areas. *AUTEX Research Journal* 18 (2):181–91. doi:10.1515/aut-2017-0019.

Zulifqar, A., T. Hua, and H. Hu. 2018. Development of uni-stretch woven fabrics with zero and negative Poisson's ratio. *Textile Research Journal* 88 (18):2076–92. doi:10.1177/0040517517715095.