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Investigation on impact of bell pique weft knit fabrics on geometric and comfort properties

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This study investigates the thermal comfort and moisture management properties of knitted fabrics using two different pique knit structures: single tuck pique and bell pique. The impact of knit structure on various geometric and comfort properties is evaluated, including loop length, wales per inch, course per inch, tightness factor, bursting strength, fabric thickness, GSM, fabric stretch, air permeability, warmth retention rate, thermal transmittance coefficient, thermal resistance, CLO, and moisture management. To construct the fabrics, a yarn linear density of 24s Ne is used, and three different loop lengths (0.265 cm, 0.285 cm, and 0.305 cm) are tested for each knit structure. The goal of this research is to compare the performance of these two knit structures and determine how they affect the comfort properties of the resulting fabrics. It is observed that the bell pique structure exhibits better comfort properties than single tuck pique at two loop lengths, and it may help the fabric manufacturers and designers in selecting the appropriate fabric structure based on the desired comfort properties.

Keywords: Air-permeability, Comfort, Thermal comfort, Thermal conductivity, Thermal resistance, Yarn linear density

1 Introduction

Comfort is a crucial aspect of clothing and encompasses various factors, such as thermal resistance, air and water vapour permeability, and liquid water resistance that contribute to the thermal comfort of a clothed body[1-2]. Evaluating the comfort of a clothing product is fundamental to its selection. In addition to thermal comfort, factors such as softness, flexibility, and moisture diffusion also influence clothing comfort. Recent textile research has concentrated on the thermal comfort properties of fabrics, which are affected by factors such as fabric structure, density, humidity, fibre and material type, weaving technique, surface treatment, finish, compressibility, air permeability, and surrounding temperature[3-5]. The comfort properties of textile materials are determined by a range of factors, including fibre type, spinning technology, yarn linear density, twist, hairiness, fabric thickness, cover factor, porosity, and finish[6-8].

Functional clothing is engineered to sustain a consistent microclimate close to the skin, which aids the body's thermoregulatory system even in the face of changing external conditions and physical activity[7,8]. To provide effective protection in a cold environment, previous research has identified three key factors: metabolic heat, environmental conditions (including temperature, humidity, and wind speed), and fabric/garment properties (such as thermal insulation, air permeability, and moisture vapour transmission). Failure to allow for adequate moisture vapour transmission can result in the accumulation of water vapour in the outer layers of the garment or on the inner side of the shell fabric, leading to discomfort for the wearer[9-10].

This research aims to comparatively evaluate the thermal and moisture management properties of two pique knit structures, the single tuck pique structure and the bell pique structure, to assess their comfort properties.

2 Materials and Methods

2.1 Fabric Structures

2.1.1 Structure No. 1: Single Tuck Pique

To create the sample, 24s Ne 100 % combed cotton yarn was knitted using a single tuck pique structure with the knit-and-tuck cam combination with three

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different loop lengths: 0.265 cm, 0.285 cm, and 0.305 cm. The resulting samples were labelled as PQ265, PQ285, and PQ305 for easy identification purposes.

2.1.2 Structure No. 2: Bell Pique

To create the sample, 24s Ne 100 % combed cotton yarn is knitted using a bell pique structure with the knit, tuck and miss cam combination with three loop lengths: 0.265 cm, 0.285 cm, and 0.305 cm. The resulting samples were labelled as BPQ265, BPQ285, and BPQ305, respectively.

2.2 Preparation of Fabric Samples

The single tuck pique and bell pique structures were produced using 24s 100 % cotton yarn, both possessing the same twist level (TM=3.4). The fabrics were produced using a Mayer & Cie single jersey knitting machine (Model: D4 2.2 E12) featuring a 24-gauge, 26” diameter, operating at 30 rpm, 84 feeders, and 1960 needles. The knitting room temperature was maintained at 30+/-2 °C with 65 % humidity. Samples were created with a loop length of 0.265 cm, 0.285 cm, and 0.305 cm. The knitting was processed with uniform machine settings, followed by processing the fabrics on a soft flow dyeing machine and compacted using an open- width compactor. Subsequently, the sample fabrics were cut into 3-meter bits, washed in a front-loading washing machine, and then conditioned in a standard atmospheric condition for 24 h to ensure relaxation and conditioning of the samples.

2.3 Evaluation of Geometric Fabric Properties

The geometric fabric properties, such as wales per inch (WPI), courses per inch (CPI), GSM, bursting strength, fabric thickness, as well as stretch and recovery properties, including elongation, growth, and recovery, were assessed, and their outcomes were tabulated.

2.3.1 WPI, CPI, Stitch Density, Tightness Factor and Loop Shape Factor

WPI and CPI were determined using the counting glass/pick glass. Stitch density, tightness factor, and loop shape factor were calculated using the following formulas:

Stitch density = WPI x CPI

Tightness factor = square root of Tex / Loop length in cm

Loop shape factor = CPI / WPI

2.3.2 Fabric Weight (GSM)

Fabric weight was measured using a GSM cutter and an electronic weighing balance. Prior to measurement, the fabrics were allowed to relax under standard atmospheric conditions.

2.3.3 Fabric Thickness

Fabric thickness was measured using a thickness gauge after conditioning under standard atmospheric conditions.

2.3.4 Bursting Strength

Bursting strength was measured using an electronic bursting strength tester. The fabrics were allowed to relax under standard atmospheric conditions prior to testing.

2.4 Evaluation of Comfort Fabric Properties

Comfort-related properties, including CLO, thermal conductivity, thermal resistance, air permeability, and moisture management, were evaluated. CLO, thermal conductivity, and thermal resistance were measured using a thermal conductivity tester, while moisture management properties were assessed using a moisture management tester. All measurements were carried out in a controlled standard atmospheric environment (20 ± 2 °C and 65 ± 2% RH).

2.5 Testing

2.5.1 Air Permeability

Air permeability, expressed as the volume of air (cm^3/s) passing through 1 cm^2 of fabric at a pressure drop of 1 cm of water, was measured using an air permeability tester in accordance with IS: 11056-1984. Ten readings were taken for each sample, and the mean and standard deviation were calculated.

2.5.2 Thermal Conductivity Test

Thermal conductivity, thermal resistance, thermal transmittance coefficient, and CLO values were measured using a thermal conductivity tester in accordance with JIS L 1018. Three readings were taken for each sample, and mean and standard deviation values were calculated.

2.5.3 Moisture Management Test

Moisture management properties were assessed according to AATCC 195-2009 using an SDL Atlas Moisture Management Tester M-290. Parameters measured included absorption rate (ARB), one-way liquid transport capacity (R), and maximum spreading speed (SSB) on the bottom surface. The overall moisture management capacity (OMMC) was calculated from these parameters. Ten measurements were taken for each sample, with the mean and standard deviation calculated. All measurements were performed under standard atmospheric conditions (20 ± 2 °C and RH 65 ± 2 %)[5,11].

3 Results and Discussion

3.1 Geometric Properties

3.1.1 Effect on WPI, CPI, Stitch Density, Tightness Factor and Loop Shape Factor

As seen in Table 1, both single tuck and Bell pique knit structures exhibit similar behaviour. With an increase in loop length, WPI, CPI, stitch density, tightness factor, and loop shape factor all decrease. Furthermore, the bell pique structure is found to be approximately 14 % denser than the single tuck pique structure[12].

3.1.2 Effect on Fabric Weight (GSM)

The GSM (grams per square meter) of knit fabrics is influenced by various factors, including knit structure, yarn count, and dimensional characteristics. Fig. 1(a) reveals that the fabric density significantly influences fabric weight Increasing the loop length of both single tuck pique and bell pique structures leads to a decrease in fabric GSM. Notably, 100 % cotton bell pique is slightly denser than single tuck pique, resulting in a slightly higher fabric GSM. These findings suggest that fabric GSM can be effectively controlled by selecting the appropriate knit structure[13].

3.1.3 Effect on Bursting Strength

Bursting strength is affected by knit structure, yarn count, and stitch length. Fig. 1(b) shows that as stitch length increases, bursting strength decreases, due to the higher number of loops per square inch present in fabrics with shorter stitch lengths. Moreover, the bursting strength of the bell pique structure is lower than that of the single tuck pique. However, the bell pique structure still meets the commercial requirement for sufficient bursting strength.

3.1.4. Effect on Fabric Thickness

Fabric thickness is determined by factors such as loop shape, knit structure, yarn count, and loop proximity. As depicted in Fig. 2, the fabric thickness of both single tuck pique and bell pique structure increases with loop length, due to the lateral compression force exerted by the loops[14-18].

3.2 Comfort Properties

3.2.1 Effect on Air Permeability

Air permeability is closely linked to heat and moisture comfort of garments, which is a vital aspect

Table 1 — Change of WPI, CPI, stitch density, tightness factor and loop shape factor of single tuck pique and bell pique, knitted with three different loop lengths

Fabric structure	Loop length, cm	WPI	CPI	Stitch density	Tightness factor	Loop shape factor
PQ265	0.265	29	84	2436	18.7	2.896
PQ285	0.285	28	74	2072	17.4	2.642
PQ305	0.305	28	69	1932	16.3	2.464
BPQ265	0.265	32	85	2720	18.7	2.656
BPQ285	0.285	31	79	2449	17.4	2.548
BPQ305	0.305	31	71	2201	16.3	2.290

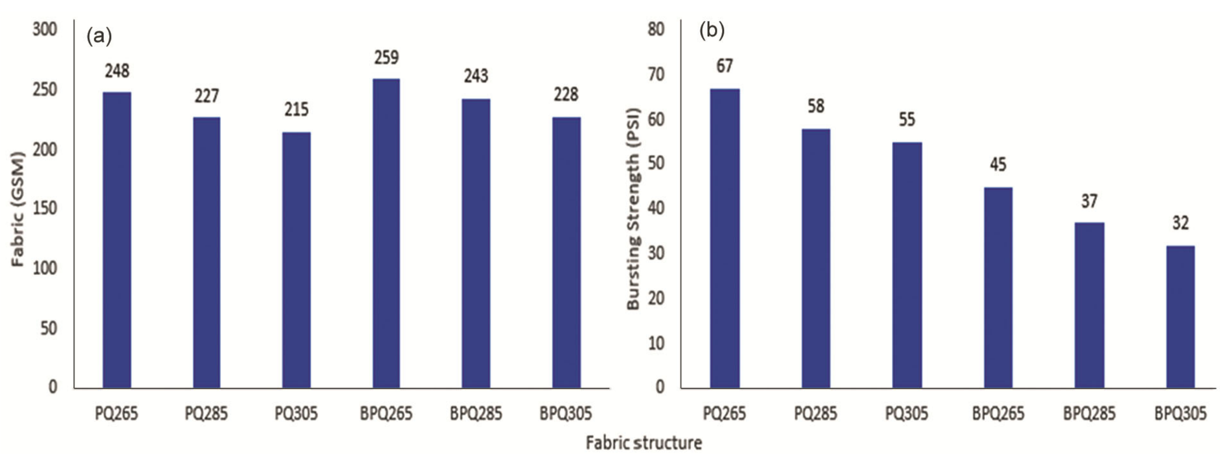

Fig. 1 — Effect of loop length and knit structure on (a) fabric GSM and (b) bursting strength

for summer sportswear. The term air permeability is often used to measure and compare the 'breathability'. For the functional breathable fabric, it is crucial that water vapour produced by the body can easily escape into the surrounding environment and prevent the penetration of liquid water from outside into the garment in order to maintain a dry feeling during wear[19-20]. Higher air permeability values indicate better breathability. As depicted in Fig. 3(a), both single tuck pique and bell pique structures exhibit increased air permeability with greater loop length, allowing more water vapour to escape and enhancing wearer comfort.

3.2.2 Effect on Warmth Retention Rate (%)

Warmth retention rate is the percentage of heat retained by a material or a garment when exposed to a certain temperature or environmental condition[21-23]. It indicates how well a material or garment can trap and hold the heat produced by the body to maintain warmth. The warmth retention rate is calculated by measuring the amount of heat that is retained by the material or garment and comparing it to the amount of heat that was originally produced. As depicted in Fig. 3(b), the warmth retention % decreases in both knit structures with an increase in loop length.

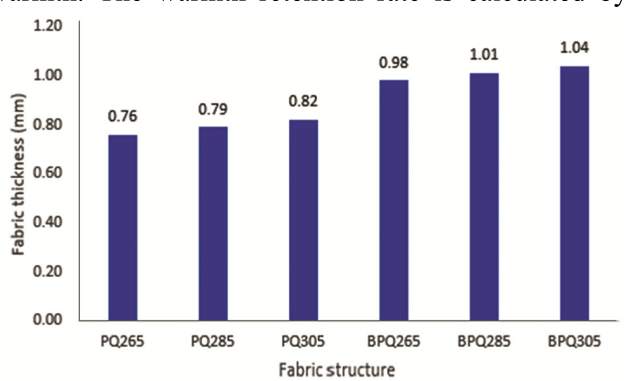

Fig. 2 — Effect of loop length and knit structure on fabric thickness

3.2.3 Effect on Thermal Transmittance

Thermal transmittance coefficient, or U-value, quantifies the rate of heat transfer through a material. It indicates the amount of heat that passes through a unit area of the material per unit time, when there is a one-degree Celsius temperature difference between the indoor and outdoor environments[24].

In simpler terms, the U-value measures how well a material or assembly can prevent heat loss or gain. The materials or assemblies with lower U-value offer superior insulation performance, as they allow less heat to pass through, minimizing heat loss. The U-value considers the material's thermal conductivity, thickness, and the presence of air gaps or insulation layers, along with other factors. As illustrated in Fig. 4(a), both knit structures show increased U-values with longer loop lengths, indicating reduced insulation performance.

3.2.4 Effect on Thermal Resistance

Thermal resistance ($m^2.K/W$) indicates how effectively a material or assembly can resist the flow of heat. It is the reciprocal of the thermal transmittance coefficient (U-value) and is expressed in square meters per degree Celsius per watt ($m^2.K/W$).

Thermal resistance indicates how much thermal resistance a material or assembly provides for a given thickness. A higher thermal resistance value indicates

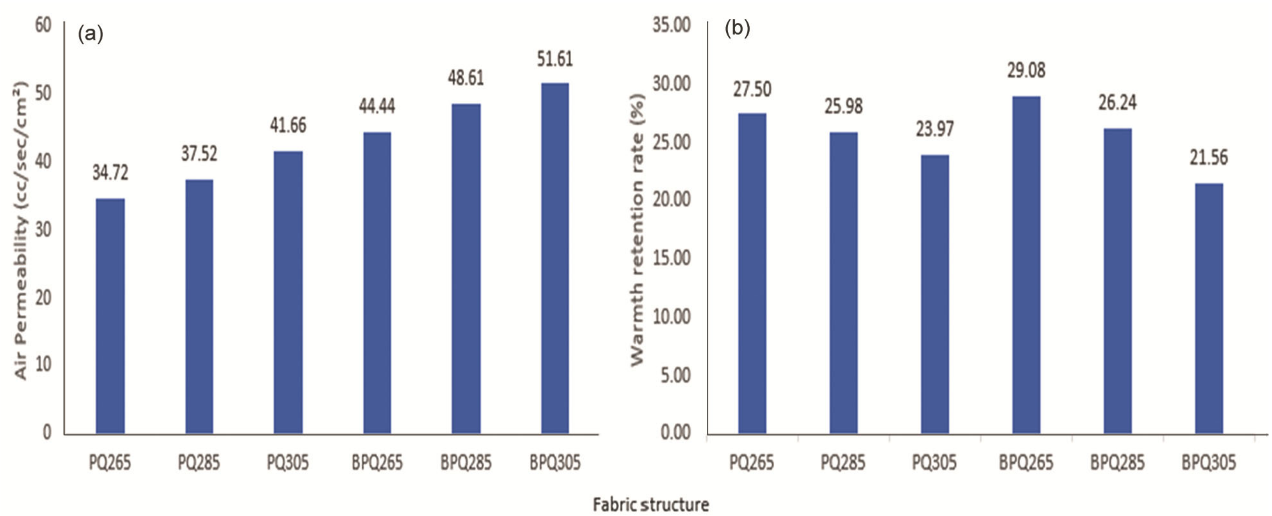

Fig. 3 — Effect of loop length and knit structure on (a) air permeability and (b) warmth retention rate %

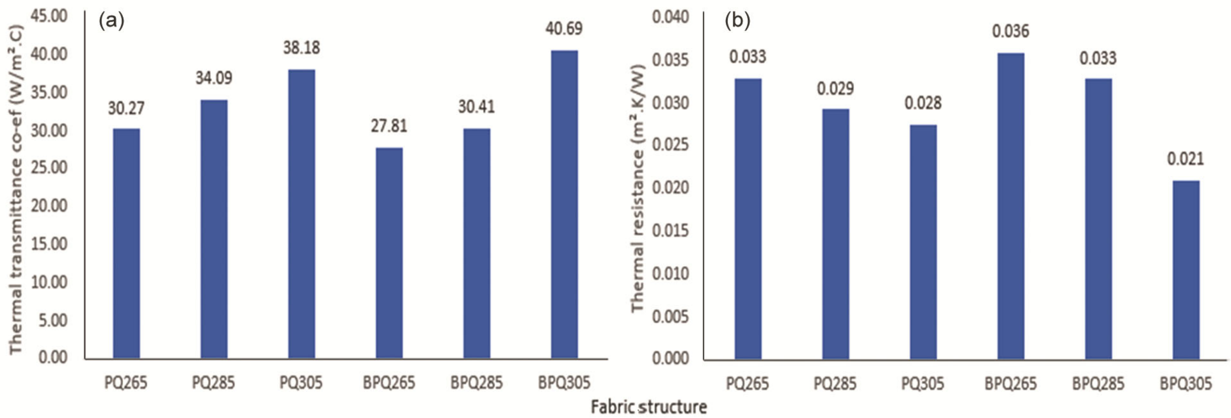

Fig. 4 — Effect of loop length and knit structure on (a) thermal transmittance and (b) thermal resistance

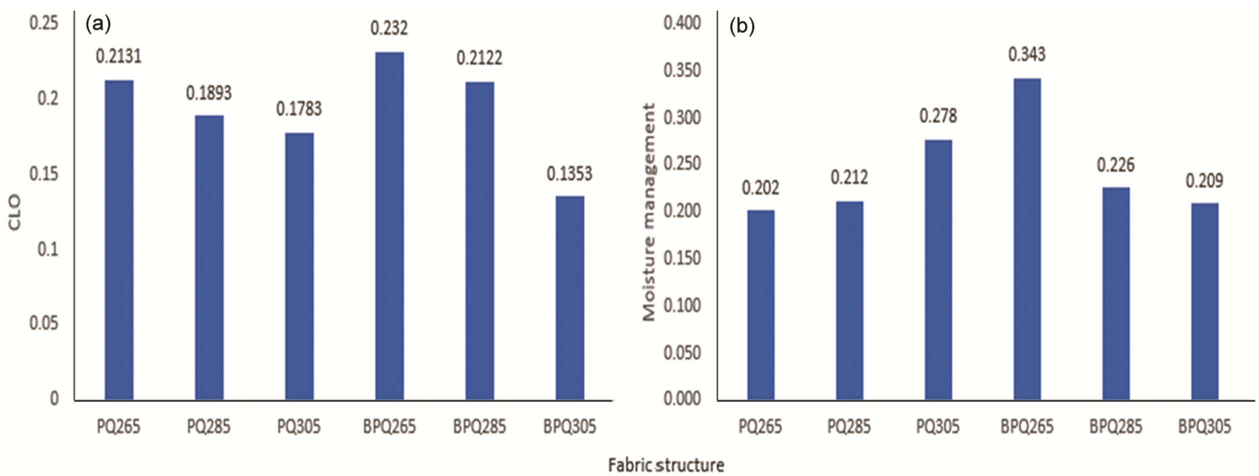

Fig. 5 — Effect of loop length and knit structure on (a) CLO and (b) moisture management

a greater ability of the material to resist heat transfer. Thermal resistance takes into account the thickness of the material or assembly and its thermal conductivity, which reflects the speed at which heat travels through the material[25]. As illustrated in Fig. 4(b), the thermal resistance of both knit structures decreases with increasing loop length, reflecting reduced ability to resist heat transfer.

3.2.5 Effect on CLO

CLO value is a unit of thermal insulation used in the textile and clothing industry to measure the thermal resistance, or insulating ability, of clothing. The CLO value indicates how much insulation a garment provides under specific conditions, such as a certain temperature and humidity level.

One CLO is equivalent to the amount of insulation needed to maintain thermal comfort in a resting human body in a neutral environment, that is, an environment with a temperature of 21 °C (70 °C) and a 50 % humidity level. For example, a garment with a CLO value of 2 provides twice as much insulation as a garment with a CLO value of 1 under the same conditions. As depicted in Fig. 5(a), the CLO value of both single tuck pique and bell pique structures decreases with an increase in loop length, confirming that higher loop lengths provide less insulation.

3.2.6 Effect on Moisture Management

Moisture management refers to the ability of a textile material or garment to manage the transfer and diffusion of moisture, including sweat and water vapour, away from the skin to maintain comfort and performance Effective moisture management requires moving and dispersing moisture from the surface of the skin to the outer layer of the textile, allowing it to evaporate into the environment[21-25]. As depicted in Fig. 5(b), the Moisture management of single tuck pique increases as the loop length increases, whereas in Bell pique it decreases as the loop length increases and Table 2 explains the mean top & bottom wetting time, mean top & bottom absorption rate %, mean top

Table 2 — Effect of loop length and knit structure on moisture management of single tuck pique and bell pique knit structures

Fabric structure	PQ265	PQ285	PQ305	BPQ265	BPQ285	BPQ305
Wetting time (top), s	5.81	4.67	4.41	4.88	5.08	7.95
Wetting time (bottom), s	5.72	4.50	4.59	4.78	5.57	9.72
Absorption rate (top), %/s	26.38	19.69	21.87	17.39	21.38	27.07
Absorption rate (bottom), %/s	46.79	20.12	28.60	31.01	26.80	27.58
Max wetted radius (top), mm	5	15	15	15	15	12
Max wetted radius (bottom), mm	5	15	15	15	15	12
Spreading speed (top), mm/s	0.83	2.38	2.53	2.25	2.18	1.61
Spreading speed (bottom), mm/s	0.85	2.40	2.40	2.15	2.06	1.49
Accumulative one-way transport index	39.56	1.54	48.62	119.99	31.71	45.38
OMMC	0.202	0.212	0.278	0.343	0.226	0.209
Moisture management results	Water repellent fabric	Fabric that absorbs moisture slowly and also dries slowly.	Fabric that absorbs moisture slowly and also dries slowly.	Moisture management fabric	Fabric that absorbs moisture quickly but dries slowly.	Fabric that absorbs moisture quickly but dries slowly.

& bottom wetted radius, mean top & bottom spreading speed, accumulative one-way transport index and mean OMMC overall moisture management capacity of single tuck pique and bell pique at three different loop lengths.

4 Conclusion

In this investigation, it can be concluded that the bell pique fabric structure has significant differences when compared to single tuck pique fabric structure in terms of all geometric properties except bursting strength at all three loop lengths and various comfort properties such as air permeability, warmth retention rate, thermal transmittance coefficient, thermal resistance, CLO, and moisture management at 0.265 cm and 0.285 cm loop lengths, except at 0.305 cm loop length. The results indicate that the bell pique structure provides better comfort properties at loop lengths of 0.265 cm and 0.285 cm, while the single tuck pique structure is better at 0.305 cm. These findings can be useful for fabric manufacturers and designers in selecting the appropriate fabric structure and loop length for specific end-uses based on the desired comfort properties.

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