

EFFECT OF LYCRA WEIGHT PERCENT AND LOOP LENGTH ON THERMO-PHYSIOLOGICAL PROPERTIES OF ELASTIC SINGLE JERSEY KNITTED FABRIC

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Abstract:

The aim of this work is to estimate the effect of loop length and Lycra weight percent (Lwp) on the geometrical and thermo-physiological comfort of elastic plain knitted fabric. Fifty single jersey knitted fabric samples were produced at five levels of Lycra weight percent (Lwp) (4%, 5%, 6%, 7%, and 8%) and loop length (2.7 mm, 2.9 mm, 3.1 mm, 3.3 mm, and 3.4 mm) with full plaited (fp) and half plaited (hp) of bare Lycra. The thermo-physiological comfort properties (thermal conductivity, absorptivity, and water vapor permeability), air permeability, and geometrical properties were measured at standard of each one. The results showed that the elastic single jersey knitted fabric thickness ranged between 3.12 times and 4.2 times of the yarn diameter (d). The fabric thickness increased when loop length is increased and decreased when Lwp is increased. The thermal conductivity, absorptivity, and water vapor resistance (WVR) decreased with Lwp increasing.

Keywords:

Thermo-physiological comfort properties, Lycra weight percent, elastic knitted fabric, fabric thickness, thermal conductivity, water vapor resistance, full plaited, half plaited.

1. Introduction

The human body tries to maintain a constant core temperature of about 37°C and a rise or fall of $\pm 5^\circ\text{C}$ can be fatal. The human body continuously generates heat by its metabolic processes. The heat is lost from the surface of the body by convection, radiation, evaporation, and respiration [1]. The body heat balance varies with the climatic conditions; the problem is one of heat dissipation in hot climates whereas in cold climates it is one of heat conservation. Clothing plays an important role in the maintenance of heat balance as it modifies the heat loss from the skin surface and at the same time has the secondary effect of altering the moisture transmission from the skin [2]. The general clothing assemblies approximately cover around 90% of a human body. Therefore, the heat and moisture transmission behavior of a fabric plays a very important role in maintaining thermo-physiological comfort [1]. The thermo-physiological properties of a fabric depend on fabrics and yarns construction parameters, fibers type and their properties. The fabrics have varying degrees of flexibility based on structural parameters [3]. Single jersey knitted fabrics (SJKF) are used for under- and outer-wear compared to woven fabrics because of their high extensibility (compression and elongation of individual stitch) [4]. To enhance the dimensional stability and maintain the dimensions during use and after repeated stresses of knitted fabrics, the additional Lycra (full- and half-plaited) and core-spun yarn are used [5]. Lycra is the trade name of elastane (spandex) yarns.

During the past few decades, many researchers were concerned with the thermo-physiological properties of knitted fabrics while some others were concerned with the effect of Lycra on the geometrical and physical properties of elastic knitted fabric. The dimensional and physical properties of cotton/spandex single jersey fabrics were investigated and compared to 100% cotton knitted fabrics. The presence of spandex increased the fabric weight and thickness; however, it decreased air permeability, pilling grade, and spirality [6, 7]. The geometrical characteristics of core spun cotton/spandex interlock structures with high, medium, and low tightness factors were studied under dry-, wet-, and full-relaxation conditions. The elastic interlock samples had higher dimensional constants compared to 100% cotton samples, and core cotton/spandex yarns increased tightness factors during relaxation states [8]. The effects of spandex type, the tightness factor of the base, and spandex yarn on the dimensional and physical properties of cotton/spandex single jersey fabrics were investigated. The fabrics knitted with spandex yarns that have the largest tension values under a constant draw ratio give the highest weight, courses/cm, stitches/cm, thickness, and lowest air permeability values [9]. The relation between Lycra consumption and fabric dimensional and elastic behavior of cotton/Lycra plaited plain knitted fabrics was studied. The results showed that Lycra proportion inside fabric has an incidence on fabric width, weight, and elasticity [10]. The effect of spandex yarn input tension, yarn loop length, and spandex yarn linear density on the elastic properties of spandex knitted fabrics was studied. The stitch density, fabric weight, and thickness of spandex fabrics were higher and fabric growth was lower than the fabric knitted



without spandex [11]. The effect of extension percent of bare Lycra yarns during loop formation on the geometrical, physical, and mechanical properties of plain jersey fabrics was studied. Results showed that for the full plaited (fp) and half plaited (hp) plaited fabrics, the stitch density, fabric thickness, and weight increased, while air permeability, the initial elasticity modulus, and the breaking load and extension decreased considerably compared to 100% cotton knitted fabric [4]. The impact of the raw material, count of yarn, pattern, and elastomeric yarn ratio on the performance and physical properties of the plain, pique, double-pique and fleeced elastic knitted fabrics was ascertained. Test results showed that raw material, yarn count, and elastomer ratio were effective on bursting strength [12]. The physical, dimensional, and mechanical properties of back plaited cotton/spandex SJKF were investigated and compared to knitted fabrics made from 100% cotton and the effect of spandex percentage was also studied. It was found that the presence of Lycra in SJKF increased course density, fabric thickness, and fabric recovery, while fabric width, fabric porosity, and extension were decreased [13]. 100% cotton, half-plaited and full-plaited, and plain and rib fabrics were investigated for physical, dimensional, geometrical, and some comfort properties and compared to each other. The results showed that transfer wicking ratios of the half-plaited fabrics were the highest, whereas the transfer wicking ratios of the full-plaited fabrics were the lowest, and extension under constant load and residual deformation ratios decreased with the addition of spandex and the increase of spandex content [14].

Only a few researchers were concerned with the thermal comfort properties of elastic knitted fabrics. The thermal comfort properties of some Egyptian stretch knitted fabrics made from synthetic- and Lycra-yarns-based single jersey were statistically investigated. The results showed that both the thermal conductivity and resistance of all the selected fabric samples increased with the increase of fabric density, and the fabric temperature variation decreased with increase of fabric thickness [15]. The physical, strength, and thermal comfort characteristics of the interlock knitted fabric by cotton and elastane yarns (full and half plaited) were investigated and compared to 100% cotton fabrics. It was ascertained that the elastic fabrics knitted by coarser elastane yarn had higher weight, thickness, bursting strength, and puncture resistance. In terms of thermal comfort, the fabrics including coarser elastane yarn provided higher thermal conductivity and thermal absorptivity, and lower air and relative water vapor permeability. As elastane

rate increased, the fabric weight, thickness, bursting strength, puncture resistance, and thermal absorptivity increased while the air permeability decreased and the fabrics knitted using elastane yarns presented higher thermal conductivity [16]. The properties of cotton SJKF produced from cotton/spandex yarns at different Lycra states (100% cotton, fp, core and dual core) were evaluated. It was noticed that the air permeability, total hand value, overall moisture management capacity, and the water vapor permeability of stretched SJKF are lower than the corresponding values for 100% cotton fabric sample. Thermal absorptivity of core and dual-core samples increased when compared to 100% cotton fabric sample [5]. The thermal comfort properties of SJKF produced from cotton/Lycra core spun yarn and cotton/additional Lycra (fp) were investigated. It was reported that there is a convergence of the measured properties' values between the fabric samples produced from core spun yarn and cotton yarns with additional Lycra. Lycra state had a significant effect on thermal conductivity and air permeability and an insignificant effect on thermal resistance, absorptivity, and relative water vapor permeability [17]. So, more researches are required to investigate the effect of Lycra percent, loop length, and Lycra state on thermo-physiological properties of elastic knitted fabrics.

Lycra proportion is one of the most important parameters of single jersey plaited fabrics and influences fabric characteristic [10]. So, this paper aims to estimate the effect of loop length and Lwp on the geometrical and thermo-physiological comfort of elastic plain knitted fabric.

2. Experimental

2.1. Materials

Fifty elastic plain knitted fabric samples were produced on VIGNONI SJ-B (number of feeders: 57, diameter: 19-inch, machine gauge: 24 needles/inch) at five levels of loop length and Lwp with full and half plaiting techniques, as shown in Table 1. All samples were produced from cotton yarn count 35/1 Ne (Egyptian Giza 86, twist multiplier 3.6) and Lycra count is 30 and 70 dTex for full and half plaited, respectively, to get the same Lwp. Lycra yarns are incorporated using plaiting technique as shown in Figure 1 and the adjustment of elastane percentage is obtained by adjusting and optimizing the speed of elastane delivery system. To increase Lwp, the tension on

Table 1. Samples specifications

Lycra state		fp					hp				
Lwp (%)		4%	5%	6%	7%	8%	4%	5%	6%	7%	8%
Loop length (mm)	2.7	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	2.9	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	3.1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	3.3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	3.4	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

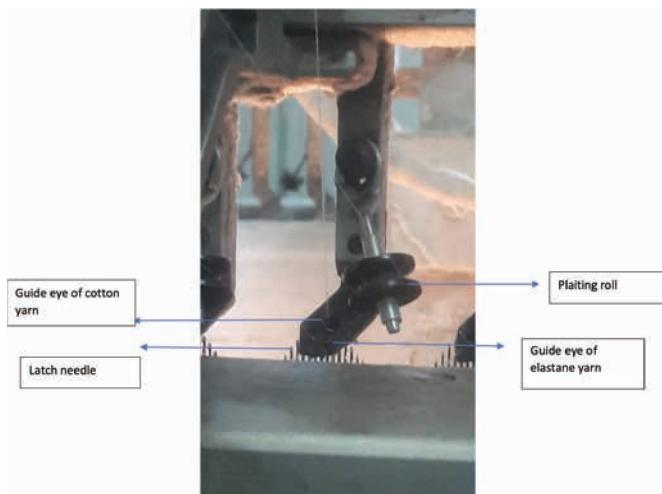


Figure 1. Plaiting technique in knitting machine.

Lycra yarns is decreased and vice versa. All fabric samples were treated according to elastic knitted fabric finishing recipe.

2.2. Methods

Fabric thickness was measured according to EN ISO 5084, 1996, at pressure 1 kPa. The fabric bulk density was calculating from the following formula [18]:

$$\text{Bulk density}(\text{kg}/\text{m}^3) = \left(\frac{W \text{ g}/\text{m}^2}{t (\text{mm})} \right)$$

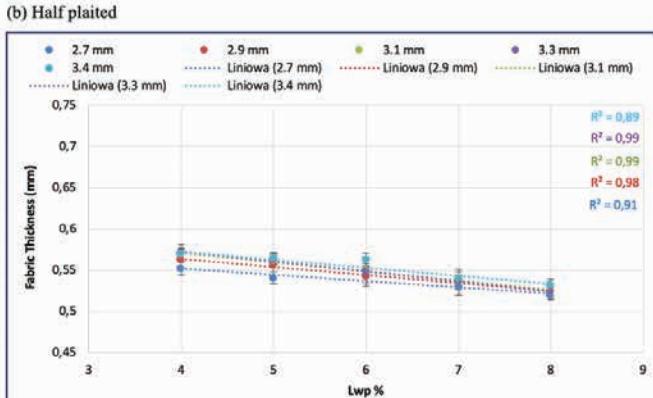
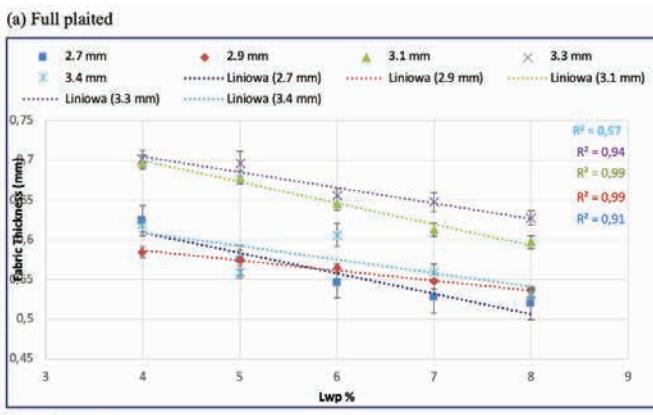


Figure 2. Effect of loop length on the fabric thickness: (a) Full plaited, (b) Half plaited.

where W represents fabric weight per unit area ($\text{g} \cdot \text{m}^{-2}$) and t fabric thickness (mm).

Thermal conductivity, resistance, and absorptivity were measured by using ALAMBETA tester according to the standard ISO 8301. Relative water vapor permeability was tested by PERMETEST according to ISO 11092. Air permeability was measured according to EN ISO 9237. The statistical Multivariate Analysis of Variance (MANOVA) was performed for the experimental results by using SPSS 15 program to determine the significance effects of the loop length and Lwp on all tested properties for full and half plaited techniques with 95% significant level.

3. Results and discussion

3.1. Fabric thickness

Figures 2(a, b) display the effect of Lwp on the fabric thickness of full and half plaited plain knitted fabric, respectively, at five levels of loop length (2.7 mm, 2.9 mm, 3.1 mm, 3.3 mm, and 3.4 mm). The fabric thickness equals twice of the yarn diameter for jamming condition, as shown in Figure 3(a), and the range of thickness of experimental samples is in between 3.12d (0.5190 mm) and 4.2d (0.7005 mm), where d is the yarn diameter. So, it could be interpreted that Lycra leads to stitch overlapping, as shown in Figure 3(b), which significantly increases the fabric thickness.

In general, for fp and hp, the fabrics' thickness decreased with increasing of Lwp from 4% to 8% by 17% and 14% at loop lengths 2.7 mm and 3.4 mm, respectively, for fp; and by 6% at loop lengths 2.7 mm and 3.4 mm for hp. It may be interpreted that the increase of Lwp reduced the stretch ability as well as the compression effect of Lycra on loops, as shown in Figures 3(c, d), and reduced the stitch density as well, as shown in

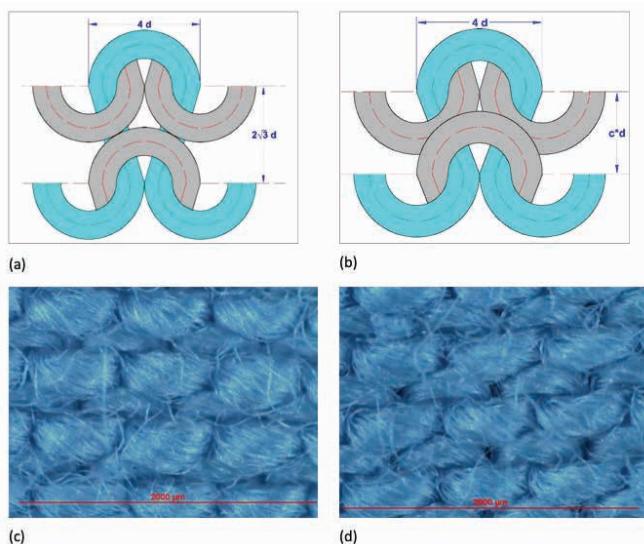


Figure 3. Single jersey loop structure: (a) Theoretical geometry of single jersey loop structure at jamming condition, (b) stitch overlapping, d is yarn diameter and $c < 2\sqrt{3}$, (c) microscopic structure image at loop length 2.9 mm and Lwp 4%, (d) microscopic structure image at loop length 2.9 mm and Lwp 8%. Lwp, Lycra weight percent.

Table 2. The results of variance analysis (p-value at significant level 95%).

Dependent property	p-value, independent variable for fp	p-value, independent variable for hp
	Loop length	Lwp
Fabric thickness (mm)	<0.001	<0.001
Thermal conductivity (mW · m ⁻¹ · K ⁻¹)	<0.001	<0.001
Thermal Absorptivity (W.m ⁻² .S ^{1/2} .K ⁻¹)	<0.001	0.059
WVR (Pa · m ² · W ⁻¹)	<0.001	<0.001
Air permeability (mm · s ⁻¹)	<0.001	.001
		<0.001
		<0.001

Table 3. The increase of loop length increased the loop's overlapping and therefore the fabric thickness is increased as well. The thickness of fp samples is higher than hp samples; this is may be due to the Lycra plating in all courses and alternative courses. The statistical analysis showed that Lwp and loop length had a significant effect on the fabric thickness; see Table 2. Therefore, the increase of fabric thickness may lead to an increase in the thermal resistance of the tested samples.

3.2. Fabric weight

As illustrated in Figure 4(a), the fabric linear density (gsm) of fp decreased with increase in Lycra rate from 4% to 8% by 18% and 9% at loop length 2.7 mm and 3.4 mm, respectively, while the fabric weight decreased with the increase in loop length (2.7 mm to 3.4 mm) by 28% and 19% at Lwp 4% and 8%, respectively. The fabric weight of hp decreased by 4% as a result of increases in Lwp and loop length from 2.7 mm

to 3.4 mm by 16% and 17% at Lycra rates 4% and 8%, respectively, as shown in Figure 4(b).

Generally, the fabric weight decreased with an increase in loop length and Lycra rate, and this can be attributed to the fact that increasing loop length leads to decrease of stitch density, as shown in Table 3, and increasing of Lwp leads to decrease of the loop's compression effect of Lycra (overlapping). The fabric weight of fp is more than hp because of Lycra plaiting technique.

3.3. Thermal conductivity

Thermal conductivity coefficient (λ) presents the amount of heat, which passes 1 m² area of material through the distance 1 m within 1 s and the temperature difference 1 K [3].

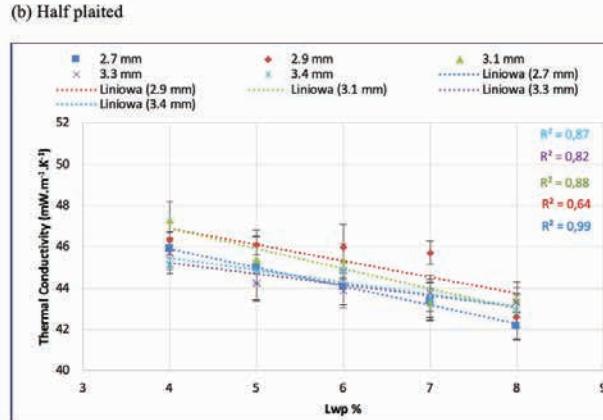
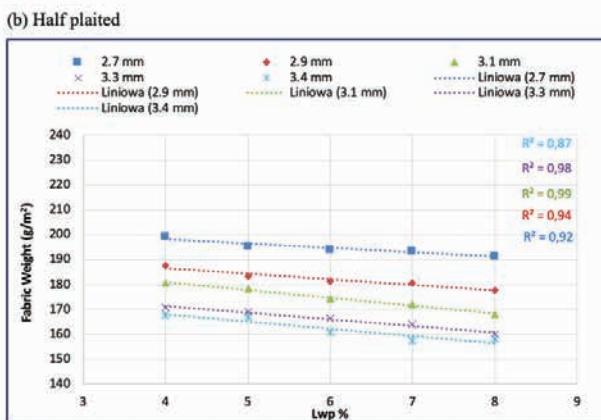
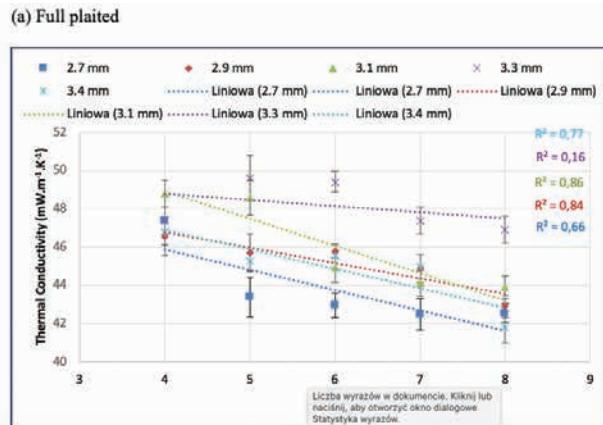
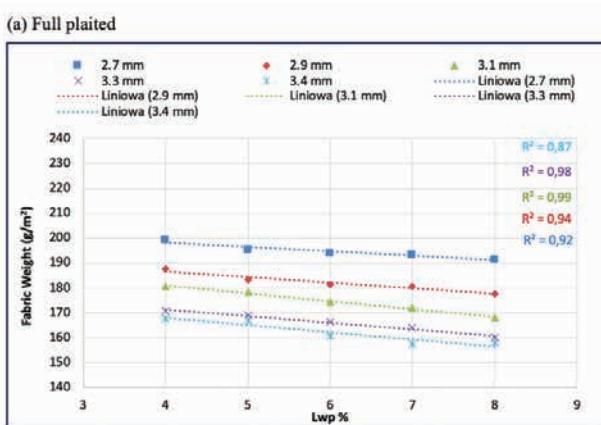


Figure 4. Effect of loop length on the fabric weight: (a) Full plaited, (b) Half plaited.

Figure 5. Effect of Lwp on the thermal conductivity: (a) Full plaited, (b) Half plaited.

Table 3. Geometrical and thermal properties.

Loop length (mm)	Lwp (%)	Stitch density · cm ⁻²		Fabric density (kg · m ⁻³)	
		fp	hp	fp	hp
2.7	4	491	432	371	361
	5	438	409	361	361
	6	422	402	364	358
	7	401	393	369	365
	8	395	391	364	369
2.9	4	396	371	334	334
	5	387	362	344	329
	6	374	361	339	335
	7	371	349	341	336
	8	356	341	341	339
3.1	4	374	333	297	317
	5	353	320	292	318
	6	334	312	296	317
	7	316	310	296	318
	8	323	302	308	321
3.3	4	353	307	279	299
	5	340	296	296	300
	6	306	291	287	303
	7	309	283	287	305
	8	293	276	291	305
3.4	4	278	286	271	295
	5	266	278	279	296
	6	280	272	285	286
	7	271	265	287	292
	8	252	256	286	297

In general, thermal conductivity decreased with the increasing of Lwp for both fp and hp, as illustrated in Figures 5(a, b) respectively. The stitch overlapping decreased with increasing of Lwp and the decreasing of stitch density are shown in Table 3. So, the number of fibers per unit area decreases, and the number of paths by which heat is transferred through the fibers by conduction is decreased. Thermal conductivity of fp increased with increasing of loop length. The statistical analysis showed that Lwp and loop length had a significant effect on the thermal conductivity; see Table 2.

3.4. Thermal absorptivity

Thermal absorptivity is the objective measurement of warm/cool feeling of the fabric. Fabrics with a lower thermal absorptivity value have warm feeling and vice versa [19].

The thermal absorptivity increases with the increasing of the thermal conductivity and fabric density according to the following equation [20].

$$b = (\lambda \rho c)^{1/2}$$

where b represents thermal absorptivity (W · S^{1/2} · m⁻² · K⁻¹), λ thermal conductivity (W · m⁻¹ · K⁻¹), ρ fabric density (kg · m⁻³), and c specific heat capacity (J · kg⁻¹ · K⁻¹).

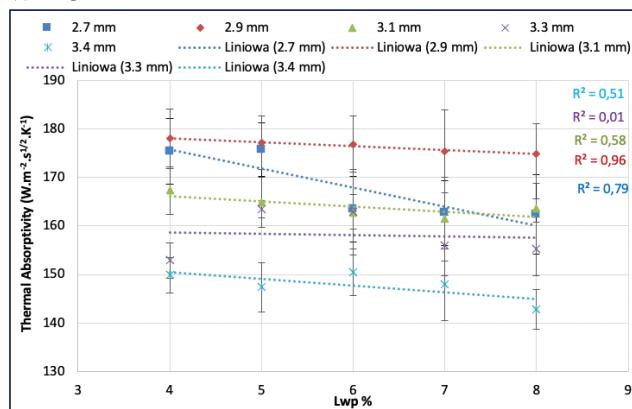
The thermal absorptivity has a strong correlation with fabric structure, fiber type, surface roughness, and contact points [21, 22] and the contact area is perpendicular to the normal line of heat flow.

The thermal absorptivity of both fp and hp decreased slightly with increase of Lwp and loop length as shown in Figure 6 and this may be due to reduction of contact points at very short time and decrease of thermal conductivity as stitch density decreases with increase of Lwp, as shown in Table 3. The thermal absorptivity of fp is higher than hp because of the formation of hp ridges on the fabric surface due to Lycra plaiting technique in alternative courses, as shown in Figure 7. So, the number of contact points in hp is less than in fp and the effective contact heat flow will be lower. The statistical analysis showed that Lwp and loop length had a significant effect on the thermal absorptivity, as shown in Table 2.

3.5. Water vapor permeability

Figure 8 shows the WVR of fp and hp SJKF at five levels of Lwp and loop length. WVR decreased with the increase in Lwp for both fp and hp. WVR values of hp were less than fp because of the formation of ridges on the fabric surface due to Lycra plaiting technique in alternative courses and the decrease in the stitch density of hp samples, thus leading to increase in pores size and water vapor transfer by diffusion through air gaps. The RWR values of both fp and hp are <5 ; so, the WVR is within excellent level of water vapor transfer. We can interpret that the all samples were produced from hydrophilic fibers and absorbed water by capillary phenomena. The loop length and Lwp had a significant effect on WVR.

(a) Full plaited



(b) Half plaited

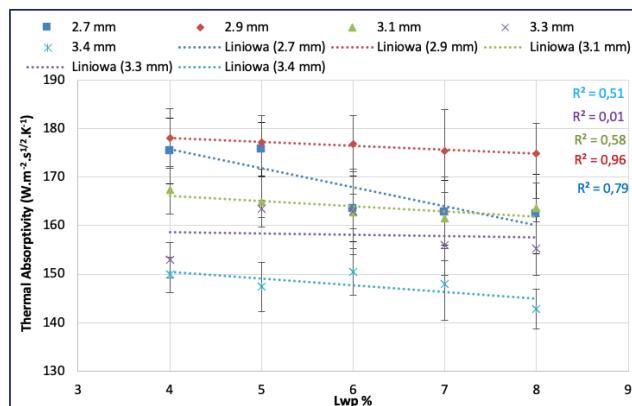


Figure 6. Effect of Lwp on the thermal absorptivity: (a) Full plaited, (b) Half plaited

(a)

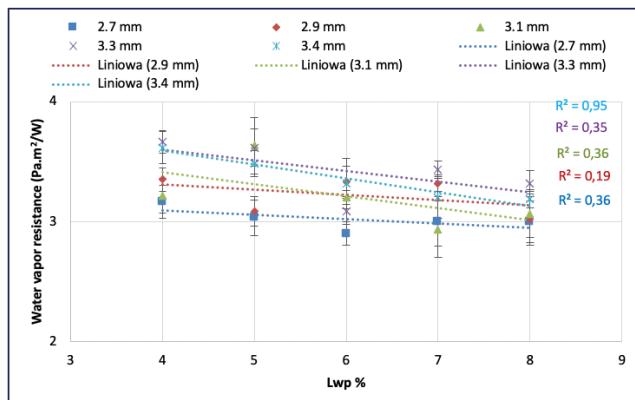


(b)



Figure 7. Microscopic back images of elastic knitted fabrics at 2.7 mm loop length and 5% Lwp: (a) Half plaited, (b) Full plaited

(a) Full plaited



(b) Half plaited

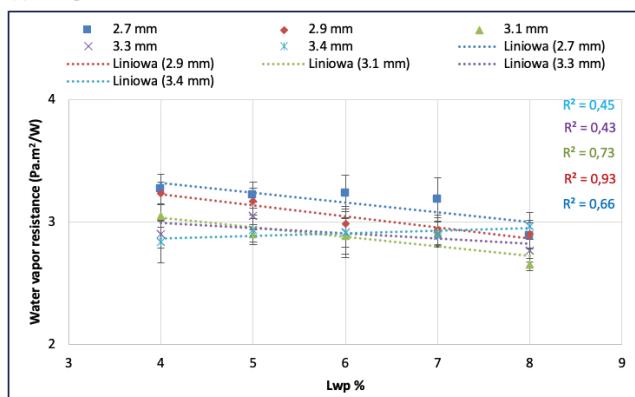
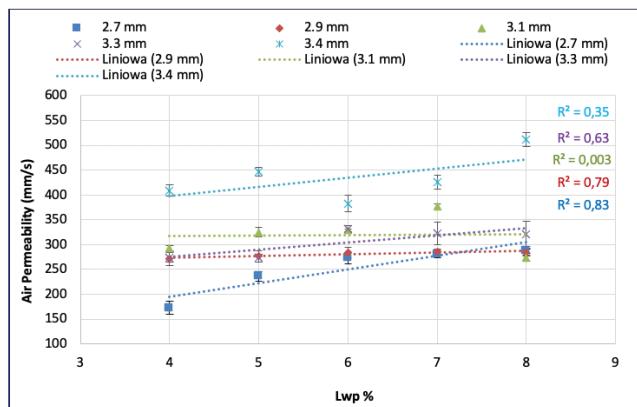


Figure 8. Effect of loop length on the water vapor resistance. (a) Full plaited, (b) Half plaited

(a) Full plaited



(b) Half plaited

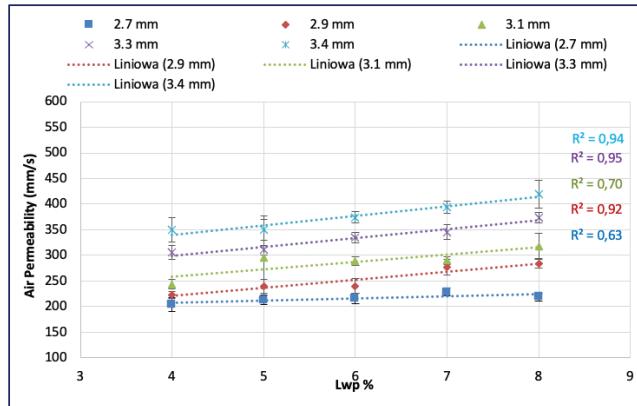


Figure 9. Effect of loop length on air permeability: (a) Full plaited, (b) Half plaited

3.6. Air permeability

Air permeability is the rate of airflow through the fabric when subjected to a pressure difference on either surface of the fabric and it is mostly affected by the fabric porosity in addition to the thickness [3, 23]. Generally, air permeability of both fp and hp elastic knitted fabrics increased with the increase in Lwp and loop length, as shown in Figure 9; this is because of the decrease of the stitch density. Therefore, the pore size increased and the rate of airflow through fabric also increased. The loop length and Lwp had a significant effect on air permeability.

4. Conclusions

The effect of loop length and Lwp on the geometrical and thermo-physiological comfort properties of full and half plaited SJKF was investigated. A total of 25 fp samples and 25 hp samples were produced at five levels of loop length and Lwp. The geometrical properties (thickness, weight, stitch density, and fabric bulk density), thermal conductivity and absorptivity, WVR, and air permeability were measured.

The results showed that:

- The range of elastic SJKF thickness was between $3.12d$ and $4.2d$ where d is yarn diameter. The fabric's thickness

decreased with increasing of Lwp and increased with the increase in loop length for both fp and hp. The fabric weight and stitch density decreased with increase in Lwp and loop length.

- The thermal conductivity, thermal absorptivity, and WVR of both fp and hp decreased with the increase in Lwp; so, the elastic SJKF could be used in summer and winter with a feeling of comfort.
- For all elastic single jersey knitted samples, the WVP values were <5 and it is within excellent level of WVR transferability, which gives comfort during wearing.
- Air permeability of both fp and hp elastic knitted fabrics went up with increase in the Lwp and loop length.
- The thermal conductivity and absorptivity and WVR values of elastic single jersey samples indicated comfort; so, adding Lycra to SJKF had a good impact on geometrical and thermo-physiological properties.

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