INVESTIGATION OF SOME SURFACE ROUGHNESS PROPERTIES OF WOVEN FABRICS PRODUCED WITH SUSTAINABLE YARNS

Gizem Karakan Günaydin[1*], Mine Akgün[2], Erhan Kenan Çeven[2,3], Nejla Çeven[4]

[1] Pamukkale University, Faculty of Architecture and Design, Department of Textile and Fashion Design, Denizli, Türkiye, ORCID ID (https://orcid.org/0000-0001-9164-3391)
[2] Bursa Uludağ University, Faculty of Engineering, Textile Engineering Department, Nilüfer, Bursa, Türkiye, ORCID ID (https://orcid.org/0000-0002-6415-7782)
[3] Bursa Uludağ University, Faculty of Engineering, Textile Engineering Department, Nilüfer, Bursa, Türkiye, ORCID ID (https://orcid.org/0000-0003-3283-4117)
[4] Vanelli Tekstil San. ve Tic.A.Ş., Organize Sanayi Bölgesi, Nilüfer, Bursa, Türkiye
[*] e-mail: ggunaydin@pau.edu.tr

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Abstract: *Biodegradable polymers have attracted attention in recent years owing to increased sensibility to waste management. Polylactic acid (PLA) fibers have been recently utilized in textile products owing to its being biodegradable with low environmental impact. PLA fibers decompose into simpler compounds, thereby minimizing their environmental impact. Woven fabrics produced from sustainable yarns such as PLA or its blends may be good alternative textile products with a sustainable manner. This research was carried out to compare the surface roughness characteristics of some woven fabrics which are plain, 2/2 twill, and 5/1 satin woven samples. Fabric samples were woven with different weft yarns (polyester, polylactic acid, and recycled polyester/Trevira) at various weft yarn densities but with the same warp yarn properties. Surface roughness values of the samples including arithmetic average height (R_a), mean height of peaks (R_{pm}), mean depth of valleys (R_{vm}) and mean slope of the profile (Δ_a) were analysed. Effect of different raw materials and fabric properties such as warp/weft density, weave pattern on surface roughness were tried to be analysed within the study.*

Keywords: PLA, woven fabrics, sustainable yarns, surface roughness.

ISTRAŽIVANJE NEKIH SVOJSTVA POVRŠINSKE HRAPAVOSTI TKANINA PROIZVEDENE OD ODRŽIVIH PREDIVA

Apstrakt: *Biorazgradivi polimeri su privukli pažnju poslednjih godina zbog povećane osetljivosti na upravljanje otpadom. Vlakna polimlečne kiseline (PLA) su nedavno korišćena u tekstilnim proizvodima zbog toga što su biorazgradiva sa malim uticajem na životnu sredinu. PLA vlakna se razlažu u jednostavnija jedinjenja, čime se minimizira njihov uticaj na životnu sredinu. Tkanine proizvedene od održivog prediva kao što je PLA ili njegove mešavine mogu biti dobri alternativni tekstilni proizvodi na održiv način. Ovo istraživanje je sprovedeno da bi se uporedile karakteristike površinske hrapavosti nekih tkanih materijala koji su uzorci običnih, 2/2 kepera i 5/1 satenskog tkanja. Uzorci tkanine su tkani sa različitim predivama potke (poliester, polimlečna kiselina i reciklirani poliester/Trevira) pri različitim gustinama potke, ali sa istim svojstvima prediva. Analizirane su vrednosti hrapavosti površine uzoraka uključujući prosečnu aritmetičku visinu (Ra), srednju visinu vrhova (Rpm), srednju dubinu dolina (Rvm) i srednji nagib profila (Da). U okviru studije pokušali su da se analiziraju uticaji različitih sirovina i osobina tkanina kao što su gustina osnove/potke, uzorak tkanja na hrapavost površine.*

Ključne reči: PLA, tkana tkanina, održiva prediva, površinska hrapavost.

1. INTRODUCTION

The yarn manufacturing or spinning process converts fibers into yarns. This process is already mechanically intensive, requiring significant energy consumption and producing solid waste, dust, and noise. Hence at least utilizing a sustainable raw material may contribute for a sustainable textile production step. Biodegradable polymers have been attracting attention as the countries get precuations about the waste increment. Biopolymers can be considered for three groups as natural biopolymers (cellulose, starch etc); synthetic polymers (polylactic acid and poly(ε-caprolactone)) and composite polymers.

PLA has many advantages such as being sourced from renewable origins like corn, being biodegradable with the help of the microorganisms in the environment where they can be fully broken down into CO_2 and H_2O. As a result of efforts to expand the use of PLA in the textile industry, woven, knitted and non-woven textile products are produced. These fibers have become popular in the textile sector as a biomass material because they provide similar properties to polyethylene terephthalate (PET). Consequently, PLA are seen as a viable alternative to traditional petrochemical-based polymers commonly used in textiles [1-10].

A good alternative for the problem of plastic disposal is PLA. Due to its being made from renewable sources, it may be totally biodegraded. PLA may be produced through the fermantation of molasses or potate starch. PLA is polymerized from lactic acid either through direct condensation or by forming a cyclic dimer intermediate known as lactide. PLA is unique as the only biobased and biodegradable polymer that can be melt-spun into textile fibers with sufficient strength on a large scale. Although other biodegradable aliphatic polyester fibers, such as polycaprolactone (PCL), polyhydroxyalkanoates (PHAs), and poly(butylene succinate) (PBS), exist, they are sourced from unsustainable petrochemical origins. PLA has lower glass transition and melting temperatures compared to PET and nylon. Compared to regenerated cellulose fibers like rayon, lyocell, and modal, PLA fiber has lower moisture regain and faster moisture transport, similar to polyester fibers. Rayon production generates toxic waste that can severely pollute the environment, whereas PLA production is non-toxic. Additionally, PLA fibers provide inherent biological resistance, excellent flame retardant properties, and strong UV resistance. PLA filaments can be obtained using melt, dry, and wet spinning process. Melt spinning process being the common method, which also allows for blending PLA with other materials (Figure 1) [11-13]. Due to the high viscosity of PLA, excessively high spinning speeds can lead to filament imperfection. Consequently, a two-step melt spinning process with lower spinning speeds is typically used instead of the direct one-step melt spinning to produce PLA multifilaments. The early literature related to some properties of fabrics from PLA yarns may be summarized as below:

Enzymatic degradation method was utilized for determining the biodegradability level of nonwovens made of PLA [14]. The study suggested a mechanism for the enzymatic breakdown of PLA nonwovens, offering potential applications for waste management in the textile industry. Additionally, core-spun yarns made from PLA and ramie fiber were developed to introduce an innovative fabrication technique that combines two-dimensional (2D) braiding with three-dimensional (3D) weaving [15]. Some reviews concerning the PLA and fabrics produced from PLA fibre blends have been performed by some researchers [16-18]. Theory of synthesis, fiber properties as well as wet treatments of PLA fabrics were investigated by Khoddami and Avinc [17]. A comparative analyse in terms of felting effect was performed between the plain and twill woven fabrics made of PLA/wool and PLA/PET blends. It was stated that improved the felting effect of PLA/wool blended fabrics was more diffucult due to lower hydrolysis resistance and thermal stability of PLA [18].

Roughness determines the texture of a fabric surface by measuring the vertical deviations from its ideal form. Larger deviations indicate a rough surface, whereas smaller deviations indicate a smooth surface. Surface roughness is a parameter that should be considered for the fabrics to evaluate their fundamental problems such as friction, contact deformation and

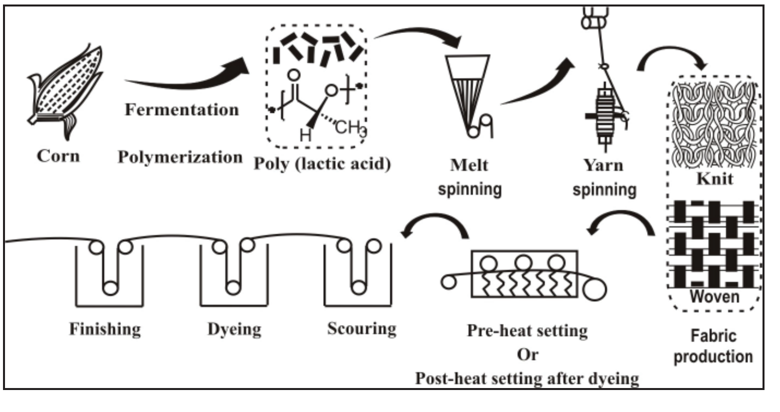


Figure 1: PLA textiles production line [13]

conduction (such as heat and electric). Roughness may be calculated in two-dimensional or three-dimensional (3D) forms [19]. It was stated that the fabric surface becomes smoother increasing threads/cm in fabric structure. This is explained with the increasing of thread/cm leading to decrement of yarn crown height. Increment of yarn diameter was also found to be leading to increment of surface roughness where high surface roughness was attributed to high interlocking of yarn crowns [20,21]. Early studies about polyester woven fabrics also revealed that fabric constructional parameters such as filament and yarn fineness, weft density, weave type influenced texture and roughness of fabrics [22,23].

As it is understood, although there have been many studies performed related to investigation of some mechanical properties of fabrics having biodegradable yarns such as PLA as raw material, there is a gap in the literature concerning the effects of fabric structural parameters (yarn type, yarn density and weave) on the surface roughness of fabrics produced from sustainable materials such as PLA, recycled polyester etc. Some main surface amplitude parameters (such as R_a, R_{pm}, R_{vm} and Δ_a) values of PLA blended woven fabrics were evaluated within this study. It was aimed to observe how the different raw materials and fabric structural parameters influenced the fabric surface roughness properties.

2. EXPERIMENTAL

2.1. Material Preparation

Fabrics having plain, 2/2 twill, and 5/1 satin weave woven with different weft yarns were produced at three different weft yarn densities for investigating the effect of fabric structural parameters on surface roughness features. Polyester, PLA, and recycled polyester/Trevira yarns were used as the weft yarns. Polyester was used as the warp yarn and the warp yarn properties (22dtex; 40 thread/cm) were kept constant in all fabrics. The fabric structural parameters are presented in Table 1. Microscopic images of fabrics were taken (Dino-Lite) with 30 times magnification. Some examples of fabrics' images with different weave pattern are presented in Figure 2.

Table 1: Fabric structural parameters

Fabric code	Weft yarn type	Weave pattern	Weft density (threads/cm)
P24	167/108 dtex/fil Intermingled Polyester	Plain	24
P26			26
P28			28
T24	167/64 dtex/fil Intermingled Recycled Polyester-Trevira (50/50%)		24
T26			26
T28			28
PL24	167/48 dtex/fil Intermingled PLA		24
PL26			26
PL28			28
P32	167/108 dtex/fil Intermingled Polyester	2/2 Twill	32
P34			34
P36			36
T32	167/64 dtex/fil Intermingled Recycled Polyester-Trevira (50/50%)		32
T34			34
T36			36
PL32	167/48 dtex/fil Intermingled PLA		32
PL34			34
PL36			36
P36	167/108 dtex/fil Intermingled Polyester	5/1 Satin	36
P38			38
P40			40
T36	167/64 dtex/fil Intermingled Recycled Polyester-Trevira (50/50%)		36
T38			38
T40			40
PL36	167/48 dtex/fil Intermingled PLA		36
PL38			38
PL40			40

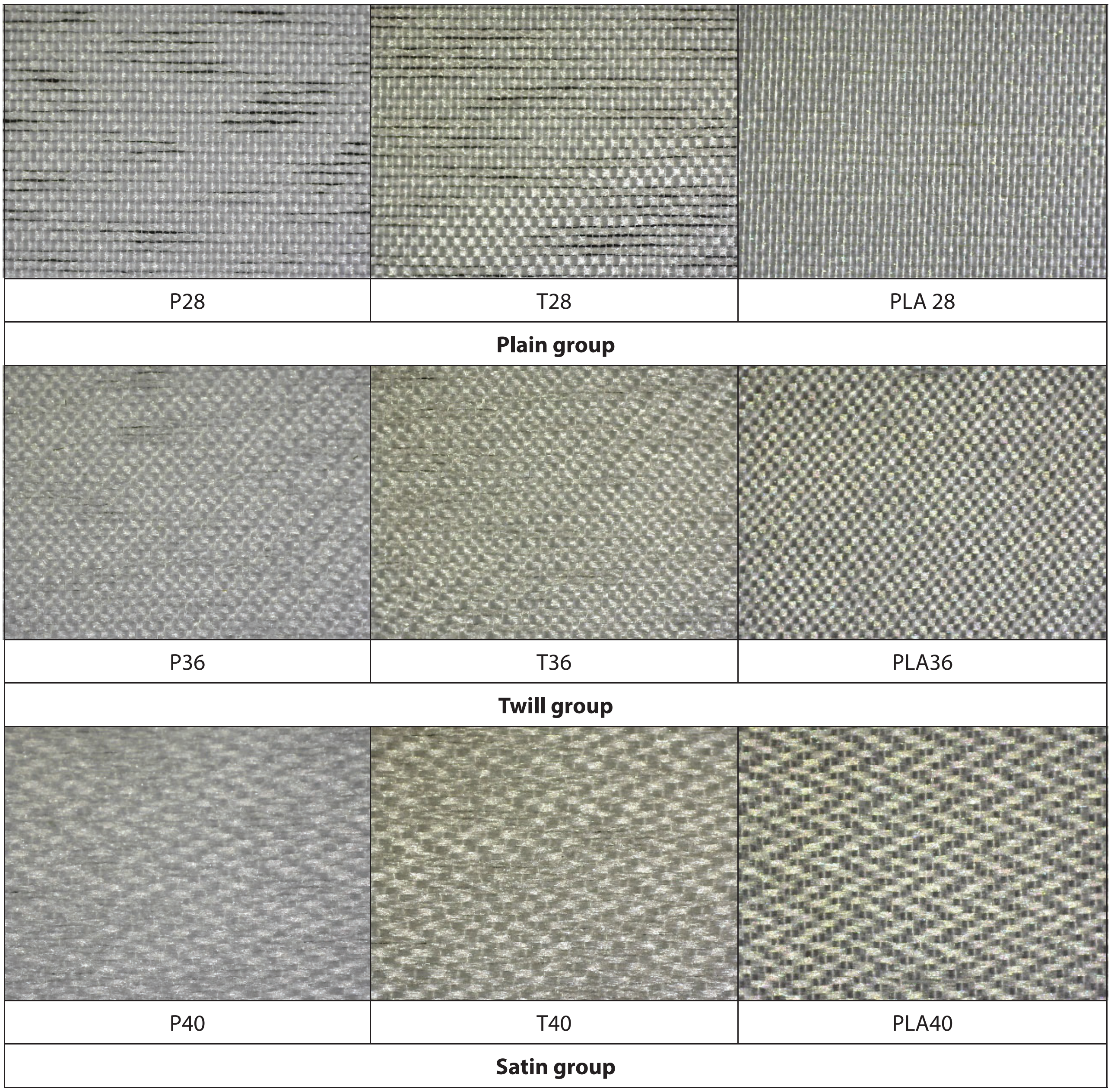


Figure 2: Microscope images of the fabrics (MAG:30X)

2.2. Method

The samples were conditioned for 24 hours under standard atmospheric conditions prior to testing. The surface roughness measurements of the samples in warp and weft direction were measured with Surfcom 130A surface roughness test device according to ISO 21920-2:2021 test standard (Figure 3) [24]. The roughness parameters were obtained with 0.8 mm cut off value in the evaluation range of 50 mm at measurement speed of 1.5 mm/sec. The amplitude parameters such as arithmetic average height (R_a), mean height of peaks (R_{pm}), mean depth of valleys (R_{vm}) and mean slope of the profile (Δ_a) values were described below [25]:

Figure 3: Surfcom 130A surface roughness test device

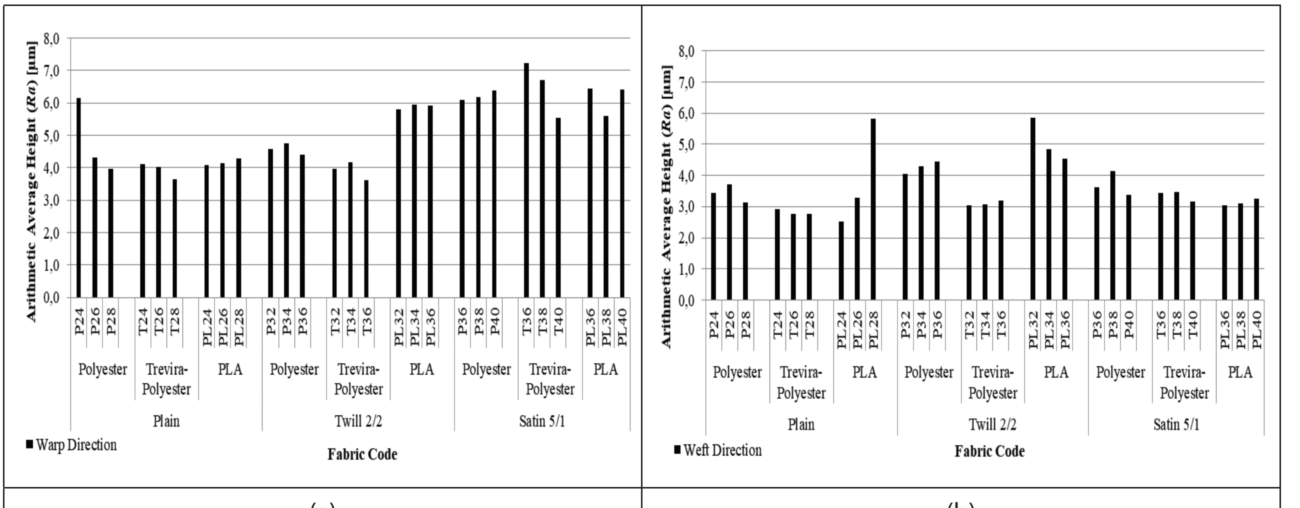
R_a, known as the center line average (CLA), is widely used as the roughness parameter. It is defined as the average absolute deviation of surface irregularities from the mean line over the length of one sample. The CLA provides a general indication of height variations but is not sensitive to minor profile fluctuations [25].

The mean value of the maximum height of peaks and the mean value of maximum depth of valleys for each sampling length may be described as R_{pm} and R_{vm}, respectively [25].

Δ_a may be described as the mean absolute profile slope over the assesment length [25].

3. RESULTS AND DISCUSSION

3.1. Arithmetic Average Height (R_a)



(a) (b)

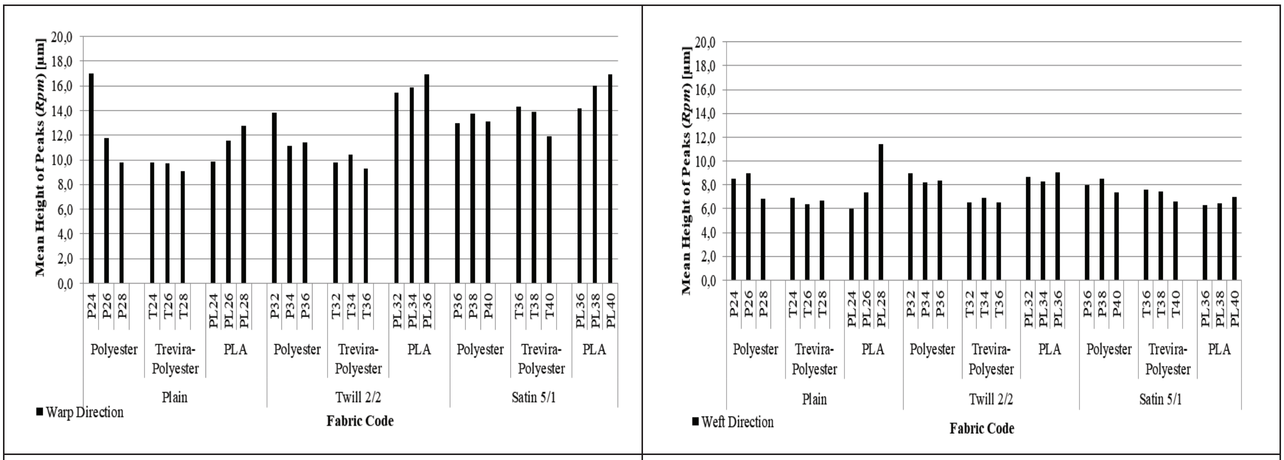
Figure 4: R_a values of fabrics at (a) warp direction, (b) weft direction

Arithmetic average height (R_a) values of fabrics in warp and weft direction were indicated in Figure 4(a) and 4(b), respectively. In Figure 4(a), it is generally showed that a decrement of R_a values of fabrics produced from polyester and polyester/Trevira weft yarn was observed as the weft yarn density increased, whereas a slight increment of R_a values of fabrics produced from PLA weft yarns. In literature [22], it is also supported that the weft density increment led to decrement of R_a values of fabrics. The observed result may be attributed to the arrangement of yarns within the fabric structure. As yarn density increased, the spaces between yarn peaks decreased, resulting in reduced surface roughness [22].

When evaluating the effects of weave structure on the R_a values of fabrics in warp direction, it was generally found that for all fabrics with plain and twill weaves (polyester, polyester/Trevira, PLA) had lower R_a values compared to satin weave fabrics except for twill farbric with PLA. For all materials, satin weave fabrics exhibited higher surface roughness values than those with plain or twill weaves. Studies in the literature also indicate that plain, twill, and satin weave fabrics generally revealed higher surface roughness values for satin weaves [19]. In the literature, it is noted that the surface roughness of fabrics woven with plain, 1/2 twill, and 1/5 satin weave increases consistently from plain to satin weave. This phenomenon could arise from the wider spacing between yarns inherent in satin weaves. The looser structure of satin weaves with lower yarn densities, particularly evident in samples woven at low weft densities, may cause the positioning of gaps within the fabric structure to shift. This can result in longer gaps and varying amplitudes, potentially increasing fabric roughness [22].

When comparing the R_a values at warp direction (Figure 4a) and weft direction (Figure 4b), the warp direction R_a values ranged from approximately 4-7 µm, while the weft direction R_a values were around 3-6 µm. This difference is thought to be due to the warp yarns (22 dtex) being much finer than the weft yarns (167 dtex). In the weft direction, the thicker weft yarns create a larger and smoother surface area on fabric surface, allowing the surface roughness device's probe to scan a smoother surface, resulting in lower R_a values compared to the warp direction. Conversely, in the warp direction, the probe scans more of the gaps and irregularities between the finer warp yarns, leading to higher R_a values in the warp direction.

3.2. Mean Height of Peaks (R_{pm})



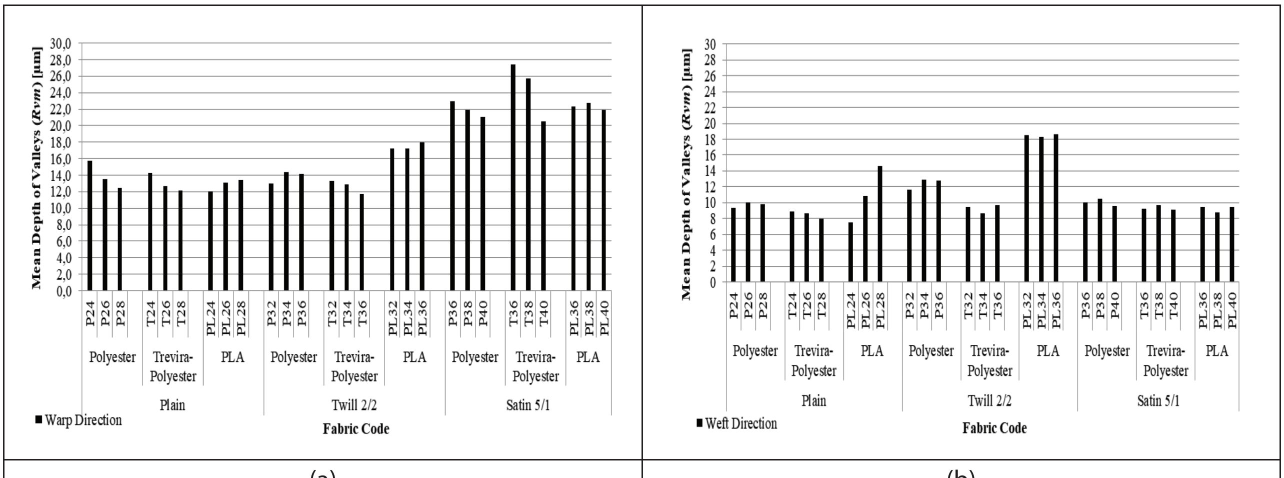
(a) (b)

Figure 5: R_{pm} values of fabrics at (a) warp direction, (b) weft direction

Mean height of peaks (R_{pm}) values of fabrics at warp and weft direction were presented in Figure 5(a) and 5(b), respectively. Figure 5 generally revealed that increasing the weft yarn density decreased the R_{pm} values for fabrics woven with polyester and polyester/Trevira weft yarns. However, for fabrics woven with PLA weft yarns, the R_{pm} values increased as the weft density increased. The increase in R_{pm} values observed with higher weft densities in fabrics woven with PLA weft yarns might be due to the number of filaments in the PLA weft yarns. The number of filaments in the PLA weft yarns (167/48 dtex/fil) is significantly lower than in the polyester (167/108 dtex/fil) and recycled polyester/Trevira (167/64 dtex/fil) weft yarns (Table 1). The number of filaments in yarn may affect the surface roughness of the fabric. It was observed that fabrics woven with yarns having a higher filament number, particularly with an increase in weft density, tended to have lower surface roughness values. Decrement in the number of filaments was observed to be resulting with higher surface roughness values.

When examining the effect of weave structure on R_{pm} values at warp direction, fabrics woven with twill and satin weave having PLA weft yarns (at high weft yarn density), and woven with plain weave having polyester weft yarns (at low weft yarn density), exhibited higher R_{pm} values. When comparing the R_{pm} values of fabrics in warp and weft direction (Figure 5a, 5b), the warp direction R_{pm} values were observed to range between approximately 10-16 µm, while the weft direction values were predominantly between ≈ 6-8 µm. This directional variation in R_{pm} values is similar with the trend observed in R_a values and could be attributed to similar reasons explained earlier. It is evident that R_{pm} values in the warp direction were significantly higher than R_{pm} values in the weft direction.

3.3. Mean Depth of Valleys (R_{vm})

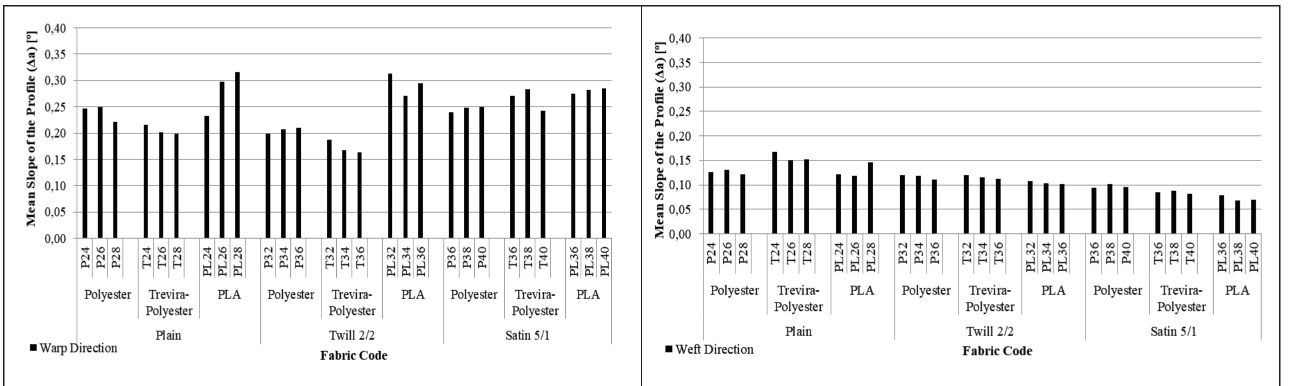


(a) (b)

Figure 6: R_{vm} values of fabrics at (a) warp direction, (b) weft direction

Mean depth of valleys (R_{vm}) values of fabrics at warp and weft direction were presented in Figure 6(a) and 6(b), respectively. In Figure 6, it was showed that an increase in the weft yarn density generally reduced the R_{vm} values of the fabric surface. When analyzing the effect of weave structure at warp direction, fabrics with plain and twill weaves revealed lower R_{vm} values, while satin weave surfaces exhibited higher R_{vm} values. In this study, the surfaces with 5/1 satin weave have higher R_{pm} (Figure 5) and R_{vm} (Figure 6) values compared to other weaves (plain and 2/2 twill). This might be due to the 5/1 satin weave creating larger peaks and deeper valleys at the yarn crsossing points, leading to increased surface roughness. When comparing the R_{vm} values of fabrics in the warp direction (Figure 6a) and the weft direction (Figure 6b), the warp direction R_{vm} values range from approximately 12-26 µm, while the weft direction values predominantly between ≈ 8-18 µm. It was observed that the warp direction R_{vm} values are significantly higher than those obtained in the weft direction. Similar to the R_a and R_{pm} values, the R_{vm} values also vary depending on the fabric direction.

3.4. Mean slope of the profile (Δ_a)



(a) (b)

Figure 7: Δ_a values of fabrics at (a) warp direction, (b) weft direction

Mean slope of the profile (Δ_a) values of fabrics at warp and weft direction were presented in Figure 7(a) and 7(b), respectively. Examining Figure 7(a), it can be seen that for fabrics woven with polyester and polyester/Trevira weft yarns, an increase in weft yarn density generally decreased the slope of the profile (Δ_a) values in the warp direction. However, for fabrics with PLA weft yarns, an increase in weft yarn density led to an increase in Δ_a values.

When analyzing the effect of weave structure on Δ_a values in the warp direction, except for fabrics with PLA weft yarns, fabrics woven with polyester and polyester/Trevira weft yarns in plain and twill weaves had lower Δ_a values than satin weave. For fabrics containing PLA weft yarns, all weave structures revealed high Δ_a values. Examining Figure 7, Δ_a values for fabrics in the warp direction ranges between approximately 0.15-0.30° degrees, while the weft direction values around between 0.10-0.15° degrees. The directional influence on Δ_a values was clearly observed. When analyzing the effect of weave structure on Δ_a values in the weft direction, the highest Δ_a values were observed in plain weave fabrics, followed by twill weave, and the lowest Δ_a in satin weave fabrics.

4. CONCLUSION

Fabric production with sustainable yarns such as polylactic acide (PLA) yarns has commonly been popular owing to the crucial requirements for protecting the environment, conserving resources, reducing waste, ensuring health and safety, meeting market demand, achieving economic benefits, complying with regulations, and securing the future of the textile industry. Utilizing of PLA in textiles supports sustainability due to its high biodegradability, renewable nature, lower energy requirements compared to some other synthetic fibers, and compatibility with most environmental processes.

Some surface roughness parameters (arithmetic average height (R_a), mean height of peaks (R_{pm}), mean depth of valleys (R_{vm}) and mean slope of the profile (Δ_a) of woven fabrics produced from polyester, recycled polyester/Trevira, and from PLA weft yarns were evaluated for the warp and weft direction among this study. Although there were some exceptions for fabrics with PLA weft yarn, it might be generally observed that, roughness parameters generally declined as the weft density increased especially in the weft direction. Additionally there were also some fluctuations for the above mentioned parameters regarding to weft yarn type or weave structure. Higher values were obtained in warp direction compared to weft direction for the measured surface roughness parameters. As a result, satisfying surface roughness values were also obtained for the fabrics with PLA weft yarns. The results might encourage the eco-conscious consumers for preferring drapery fabrics with PLA yarns.

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