An eco-friendly approach: effect of fixation time on colour and comfort properties of digital printed fabric

DOI: 10.35530/IT.074.05.2022122

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ABSTRACT – REZUMAT

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This study will examine how digital printing affects clothing comfort on knitted fabrics from different raw materials. Garments significantly affect the heat exchange between the human body and the environment. Therefore, consumers prefer thermally balanced and effective moisture-controlled products in the selection of clothing. Air permeability is also important in explaining the comfort performance of the product in the textile industry. On the other hand, digital printing machines have become the centre of attention of consumers as a print type on which the desired pattern can be printed on the chosen fabric and more ecological, faster, and economical. However different printing processes can change the comfort characteristics of the garments.

In this study, single jersey knitted fabrics 100% Ne 12/1 cotton, 100% Ne 30/1 cotton, and Ne 12/1 70% cotton + 30% Hemp were produced. Raw materials were bleached and singed, then coloured with digital printing. After that, air permeability, bursting strength, stiffness, ironing fastness, and SEM analyses were applied to samples when the results were determined, it was seen that heavier fabric will have higher stiffness. Also, thicker yarns have higher bursting strength. It follows that the cotton-hemp blended fibres (PK) have high unevenness, and the bursting strength of the fabrics produced from this raw material is lower than cotton fabrics (P12). Similarly, since the thin-thick place values of cotton-hemp blended yarns are high, porosity is one of the most important factors affecting air permeability in fabrics. This porous structure also increased the air permeability of the fabric.

Keywords: *inkjet printing, air permeability, hemp, thickener, knitted fabrics, fixation time, ironing fastness*

O abordare ecologică: influența timpului de fixare asupra proprietăților de culoare și confort ale materialului textil imprimat digital

Acest studiu va analiza modul în care imprimarea digitală afectează confortul îmbrăcămintei realizată din tricoturi din diferite materii prime. Îmbrăcămintea influențează semnificativ schimbul de căldură dintre corpul uman și mediu. Prin urmare, consumatorii preferă produse echilibrate termic și eficiente cu umiditate controlată, în selecția îmbrăcămintei. Permeabilitatea la aer este, de asemenea, importantă în explicarea performanței de confort a produsului în industria textilă. Pe de altă parte, mașinile de imprimat digital au intrat în centrul atenției consumatorilor ca tip de imprimare pe care poate fi imprimat mai ecologic, mai rapid și mai economic modelul dorit pe materialul textil ales. Cu toate acestea, diferitele procese de imprimare pot modifica caracteristicile de confort ale articolelor de îmbrăcăminte.

În acest studiu, au fost produse tricoturi glat 100% Ne 12/1 bumbac, 100% Ne 30/1 bumbac și Ne 12/1 70% bumbac + 30% cânepă. Tricoturile brute au fost albite și pârlite, apoi imprimate digital. După aceea, permeabilitatea la aer, rezistența la plesnire, rigiditatea, rezistența culorii la călcare și analizele SEM au fost determinate pentru probele studiate şi s-a demonstrat că materialul textil cu masa mai mare va avea o rigiditate mai mare. De asemenea, firele mai groase au o rezistență mai mare la rupere. Rezultă că fibrele în amestec din bumbac și cânepă (PK) au neregularităţi mari, iar rezistența la plesire a tricoturilor produse din această materie primă este mai mică decât cea a tricoturilor din bumbac (P12). În mod similar, deoarece valorile de subţiere-îngroşare ale firelor în amestec din bumbac și cânepă sunt ridicate, porozitatea este unul dintre cei mai importanți factori care afectează permeabilitatea la aer a tricoturilor. De asemenea, această structură poroasă a influențat pozitiv permeabilitatea la aer a tricotului.

Cuvinte-cheie: *imprimare cu jet de cerneală, permeabilitate la aer, cânepă, agent de îngroșare, tricoturi, timp de fixare, rezistența culorii la călcare*

INTRODUCTION

Sustainability means ensuring diversity and productivity in a system. As mentioned in the green agreement published by the Ministry of Commerce, sustainability has become a concept that covers all production stages today. In this context, with the increase in environmentally friendly approaches, the production of organic, ecological and ethical textiles has started to become widespread. New ways are being explored to find ways to stop the environmental pollution caused by textile production, to produce fabrics that do not need toxins and large amounts of water, and that minimize local damage to the ecology [1].

Within this scope, hemp fibres are defined as one of the fibres that contribute to sustainability. Hemp fibre is used in products with high added value due to its superior properties such as high strength properties, high moisture absorption and breathability, no pilling, organic products, antibacterial properties, UV protection, and good electrostatic properties. There is a wide variety of products made from hemp fibres [2]. Textile materials are often coloured to give the fabric a more attractive appearance or effect. Printing in textiles means painting limited spaces, allowing one or multi-colour patterning or regional colouring. In addition to various conventional methods such as rotation, film ruck, transfer, and roll printing, the digital (ink-jet) printing method, which has started to be the centre of attention of machine manufacturers in recent years, also finds wide use. Digital printing technology eliminates the mechanical steps in the conventional printing method. It saves time as it does not require many steps such as preparation. It also allows the necessary revisions and corrections to be made at the lowest cost.

When conventional textile printing and digital textile printing are compared, it is seen that there are big differences between them in terms of cost and the fulfilment of customer demands. In classical textile printing, pre-printing processes are required for the desired patterns and colours such as screen preparation costs. On the other hand, high-resolution and quality printing is possible without colour limitations in digital printing. In addition, the energy and water consumption consumed by conventional printing methods is largely avoided. It is known that 95% less water and 30% less electricity are used in digital printing [3–6]. In the literature on ink-jet printing, there is a lack of studies on the subject of pretreatment and steaming time. Thus, this study aims to investigate the effect of different fixation times on fabric properties using different raw materials for digital ink-jet printing and the possibilities of achieving higher colour yields, and better fastness properties. Yang et al. printed on 100% cotton fabric and a traditional setting machine and a newly designed setting machine were used for the fixation of the fabrics.

2–4 minutes at 110°C gave the best results in the conventional method. In atmospheric fixation, 15–25 minutes at 100°C were indicated as the most appropriate parameters [7]. In 2007, Yuen conducted a study on the pretreatment of 100% cotton fabrics with chitosan biopolymer. It was neutralized by passing through 2 baths, the first being acidic and the second acidic. As a result; it was observed that fabrics treated with the 2-bath method had a better colour than untreated fabrics and fabrics pre-treated with chitosan. The bacteria were destroyed after 48 hours in the 2-bath method and chitosan [8]. In Selçuk's master's thesis, the effect of pre-treatments applied to fabric in digital printing on print quality was investigated. When the results were evaluated, it was seen that the use of alkaline at the rate of 20 g/l gave the best colour and fastness results. However, the optimum value is given as 100 g/l for urea. The optimum value for the thickener chemical varies between 100 g/l and 125 g/l [5]. In Kaimouz's study, the effect of the fabrics and processes on ink penetration was examined. Tencel fabrics both have higher dye uptake than cotton. Standard Tencel has the best colour fastness. It has been determined that the dye uptake of the fabrics produced from Tencel A100 raw material is good, but the colour resistance is low [9]. In 2012, Gorgani et al. performed a one-step digital printing pre-treatment by applying 4 different organic salts at different concentrations and different pH values. It has been observed that the use of organic salts improves light fastness in all types and concentrations and increases the fixation rate. Regardless of the type, it has been stated that the pretreatment pH value of 8 gives the best results [10]. In a study conducted in 2016, the effect of pretreatment on the ink droplet spread was measured. In summary, 4 g of saturated fatty acid derivative (PT) added to sodium alginate controls the spread of the droplet. Thus, savings can be achieved in terms of ink cost [11]. Golam Kibria et al. aimed to investigate the effects of printing. Finally, after comparing the test results, it was found that the properties of the fabrics printed with thickeners in combination with sodium alginate were better than those printed with a single thickener [12].In another study, interlock knitted fabrics were coloured with digital printing. When the test results were evaluated; it was concluded that the fixing temperature had an effect on air permeability, but it did not lead to a significant change in bursting strength [13]. In experimental research, cotton and Tencel fabrics are coloured by a digital printing method. It was observed that the time-dependent rate of drying- thus the mass loss- and transfer capillary wetting ability were consistent with the results found in the literature [14]. In their study, Muhsin et al. investigated the performance of the digitally printed cotton fabric using three sustainable and formaldehyde-free cross-linkers, three different softeners, C8-free oil and water repellent, and halogen-free flame-retardant. The results show that the proposed sustainable finishes have significantly improved the performance of the digitally printed fabric as compared to the reference non-finished digitally printed sample [15]. The study which was published in 2021, aimed to optimize the process parameters. The bulk-scale experiments carried out at optimum levels have shown that an average of ca. 52% of reactive ink, 37.5% of urea and 50% of alkali can be saved by digital printing of cationized cotton along with the generation of nearly colourless effluent [16]. In a study, single jersey knitted fabrics obtained from raw materials of Cotton, Viscose, Cotton-Hemp, Cotton-Modal, and Cotton-Viscose mixed raw materials were used. All fabrics treated with a 6-minute fixation time have lower bursting strength than 10 minutes. For cotton-hemp and cotton fabrics, as the yarn number increases bursting strength increases too. The use of 150 g/l thickener for all cotton, viscose, cotton-modal and cotton-viscose fabrics reduced bursting strength for both fixation times [17]. This study aims to investigate the use of different types of thickeners as a replacement for sodium alginate in the pretreatment paste in digital ink-jet printing of cotton fabrics The results showed that sodium carboxymethyl cellulose can be used properly in the pretreatment paste for reactive ink-jet printing [18].

MATERIALS AND METHODS

Fabric production properties

The yarns used in the study were produced in a ring-spinning machine. Yarn properties are given in table 1. The samples were coded as follows: P30; Ne 30/1 100 % cotton, PK; Ne 12/1 70 % cotton+ 30 % Hemp and P12; Ne 12/1 100 % cotton.

The fabrics were produced in a single jersey knit structure at a speed of 20 rpm. The knitting process is explained in table 2.

Table 1

YARN PROPERTIES			
Yarn Properties	**P30/1**	**P12/1**	**PK**
Uniformity (%)	9.33	10.25	19.61
CV- %	11.78	13	25.37
Thin –40%	16.5	40.5	3987
Thin –50%	0	0	70
Thick +35%	187	618	5076
Thick +50%	14	86	2652
Neps +200%	15	46.5	3912
Neps +280%	3	6.5	1296
Hairiness H	4.67	7.44	9.35
B-Force (gF)	408.6	8.04	595.5
Elongation (%)	5.63	6.94	6.53
Rkm	20.76	16.11	11.61
B-Work (N.cm)	6.137	13.802	9.44

Table 2

FABRIC CONSTRUCTIONS				
Sample properties	**Yarn count (Ne)**	**Machine fineness (needle/ inch)**	**Machine diameter (inch)**	**Total number of Needles**
P30/1	30/1	28	30	2640
P12/1	12/1	12	30	1128
PK	12/1	12	30	1128

After fabrics are produced, the singeing process is applied to the fabrics. The purpose of the singeing process is to make the fabric surface smoother by removing the fibre ends from the yarns. Singeing process was carried out on one side, at a speed of 80 m/min, at 10 bar pressure, and a distance of 8–10 mm. The back position is vertical. Reactive pretreatment paste recipes were padded onto the singeing and bleaching knitted fabrics. The pretreatment pastes were prepared according to the recipe in table 3. Immediately afterwards, the fabrics were dried. Reactive pretreatment paste recipes were padded onto the singed and bleached knitted fabrics. The pretreatment pastes were prepared with thickener, sodium bicarbonate, urea, and water. After padding the paste, the fabrics were dried. A pattern was designed to evaluate the colour yield and printed

Table 3

PRETREATMENT RECIPES		
Chemicals	**Rate**	**Amount**
Beam Bender	1.25 g/l	627.5 g
Wetting Agent	2 g/l	1004 g
Caustic(48-49 Be)	4ml/l	3220 ml
Stabilized Peroxide	4% /fabric weight	2440 g
Acidic Acid	1 ml/l	805 ml
Anti-peroxide	0.7 ml/l	563.5 ml

onto the pre-treated fabrics with cyan, magenta, yellow and black reactive inks, at 540 × 360 dpi, using a Nassenger PRO60 ink-jet printer with a piezoelectric drop-on-demand print head. After the patterns dried, the printed fabrics were steamed for 6 and 10 minutes at 110°C with a steamer for the fixation of dyes. Finally, the fabrics were washed off to remove unfixed dyes and residual materials on the surface and dried. All the tests were performed under standard atmospheric conditions (temperature: 20±2°C and relative humidity: 65±2%). Physical properties of used fabrics such as yarn count, thickness and mass per unit area were determined according to TS EN 14971:2006 [19], TS 7128 EN ISO 5084 [20] and TS 251 [21] respectively. The air permeability tests were conducted according to the TS 391 EN ISO 9237 by using the Air Permeability Tester at a test pressure drop of 100 Pa (20 cm^2 test area) [22]. Characterization of digital printing on samples was using means of scanning electron microscope (SEM, FEI Quanta 650 Field EmiColour). Colour measurements of the samples were carried out by using a spectrophotometer (Minolta CM 3600) wavelength of 400–700 nm, under D65 daylight with an observer 10° angle. The colour fastness to ironing of the printed fabrics was assessed by the ISO 105-X11. This method was supposed to assess the resistance of the colour of textiles to ironing. The test was carried out for dry, damp and wet fabrics [23]. The fabric bursting strength was tested using a JH Truburst tester machine according to the BS EN 13938-2 testing method [24].

RESULTS AND DISCUSSION

The printing pattern chosen while producing the samples has been specially created in CMYK (Cyan-Magenta-Yellow-Key=black) colours to facilitate colour measurements.

The abbreviations used while coding the samples are specified as P30 Ne 30/1 cotton, PK cotton/hemp blend and P12 Ne 12/1 cotton. While analysing, the samples were evaluated separately for 4 different colours in the fabric. In the production of fabrics, the fixation process after the digital printing process was carried out at two different times, 6 minutes and 10 minutes. Some physical tests were performed on the samples in accordance with the standards. The results of these tests are given in table 4. In the

Table 4

Samples		Mass per unit area (g/m^2)		Wale per cm		Course per cm		Thickness (cm)		Loop length (cm)		Loop density (cm^2)
		Avg.	S.D.	Avg.	S.D.	Avg.	S.D.	Avg.	S.D.	Avg.	S.D.	
P30/1	6 min.	132.46	1	14.75	0.47	18.9175	0.8225	0.35675	0.0085	0.4605	0.00625	278.845
	10 min.	130.80	0.3925	14.4975	0.3525	18.0825	0.675	0.39075	0.0105	0.529	0.0105	262.25
P12/1	6 min.	197.53	0.5875	10	0.205	17.4175	0.1175	0.55925	0.0095	1.10925	0.03075	177.5
	10 min.	182.09	0.875	9.5	0.41	18.5	0.41	0.5815	0.0065	0.9855	0.031	174
PK	6 min.	141.05	0.5875	10.0825	0.5275	17.7925	0.39	0.53075	0.01575	0.88525	0.042	180
	10 min.	166.60	0.9925	10.165	0.44	17.835	0.235	0.5815	0.0215	1.133	0.0365	180

tables, the mean is expressed as Avg., and the standard deviation is expressed as S.D. When the physical test results were evaluated, it was seen that the fabric thickness and weight of the samples increased as the yarn thickness increased.
In addition, the samples were subjected to the ironing fastness (color fastness to ironing with the hot press) test, which is one of the fastness-to-use tests. Ironing fastness test results are also given in table 5. While evaluating the ironing fastness, both the results immediately after the test and the results after 4 hours were analysed in the same way. According to the results, although the values of the damp and wet measurements were low immediately after analyses, the ironing fastness values of all samples were high after 4 hours. It was concluded that these results were obtained because of the high fastness of the reactive dyestuffs. Table 6 shows the spectrophotometric colour analyses of the samples. With this Minolta brand CM 3600 model device, measurements

Table 5

IRONING FASTNESS OF FABRICS

Samples			PK		P12/1		P30/1	
			6 min.	10 min.	6 min.	10 min.	6 min.	10 min.
C	Dry	Immediately	4	4/5	4/5	4/5	4/5	4/5
		After 4 hours	5	5	5	5	5	5
	Damp	Immediately	4/5	4/5	4/5	4/5	4/5	4/5
		After 4 hours	5	5	5	5	5	5
	Wet	Immediately	3	3	3/4	3/4	3/4	3/4
		After 4 hours	4/5	4/5	4/5	5	4/5	5
M	Dry	Immediately	4/5	4/5	5	4/5	5	4/5
		After 4 hours	5	5	5	5	5	5
	Damp	Immediately	4/5	4/5	4/5	4/5	4/5	4/5
		After 4 hours	5	5	5	5	5	5
	Wet	Immediately	3	2/3	2/3	3/4	3/4	3/4
		After 4 hours	4/5	5	4/5	4/5	4/5	5
Y	Dry	Immediately	4/5	4/5	4/5	4/5	4/5	5
		After 4 hours	5	5	5	5	5	5
	Damp	Immediately	5	4/5	4/5	4/5	4/5	4/5
		After 4 hours	5	5	5	5	5	5
	Wet	Immediately	3	3	2/3	3/4	3/4	3/4
		After 4 hours	4/5	4/5	5	5	5	5
K	Dry	Immediately	4/5	4/5	4/5	5	4/5	5
		After 4 hours	4/5	5	5	5	5	5
	Damp	Immediately	4/5	4	4/5	4/5	4/5	4/5
		After 4 hours	4/5	4/5	5	5	5	5
	Wet	Immediately	2/3	2	3	3/4	3	3
		After 4 hours	4/5	4/5	5	5	5	5

Table 6

COLOR DIFFERENCES OF FABRICS				
Samples	**Colour**	**ΔE**	**Greyscale value**	**Kasikovic et al. in 2011**
PK	C	3.64	3	*ΔE < 0.4 → 5 *0.4 < ΔE < 1.25 → 4/5 *1.25 ≤ ΔE < 2.1 → 4 *2.1 ≤ ΔE < 2.95 → 3/4 *2.95 ≤ ΔE < 4.1 → 3 *4.10 ≤ ΔE < 5.8 → 2/3 *5.8 ≤ ΔE < 8.2 → 2 *8.2 ≤ ΔE < 11.6 → 1/2 *ΔE ≥ 11.6 → 1
	M	2.79	3/4	
	Y	1.81	4	
	K	2.48	3/4	
P12/1	C	2.51	3/4	
	M	2.86	3	
	Y	3.09	3	
	K	0.38	5	
P30/1	C	1.73	4	
	M	0.72	4/5	
	Y	1.35	4	
	K	0.48	4/5	

Table 7

PERFORMANCE PROPERTIES OF FABRICS							
Samples	**Fixation time (minutes)**	**Burst pressure (kPa)**		**Air permeability (mm/s)**		**Stiffness (kg-F)**	
		Avg.	**S.D.**	**Avg.**	**S.D.**	**Avg.**	**S.D.**
P30/1	6	170.9	2.826	1282.53	41.94	52.25	9.575
	10	169.12	2.839	968.83	111.686	53	4.636
P12/1	6	252,5	14.377	1784.813	34.617	118.75	17.398
	10	259.27	5.461	1455.178	48.788	150.75	18.29
PK	6	162.7	8.815	2218.71	0	114.75	32.04
	10	179.17	1.738	1921.993	49.071	116.75	10.568

were made under D65 daylight with an observer angle of 10°. The color difference ΔE value was measured for 10 minutes vs. 6 minutes' fixation times. In the study of Kasikovic et al. in 2011, the grey scale equivalent of ΔE colour difference limit values was given [25]. These values are indicated on the grey scale in the table.

The performance properties of fabrics are shown in table 7. While testing the performance properties of fabrics, measurements were made to include all CMYK colours in fabrics.

Also, it follows that the cotton-hemp blended fibres(PK) have high unevenness, and the bursting strength of the fabrics produced from this raw material is lower than cotton fabrics (P12) [26]. The results of the experimental study were evaluated statistically by Man Whitney U analysis and significant values given in table 8. Images obtained from SEM analysis are given in table 9. The magnification ratios were kept constant for each sample and images were taken at 500, 1000 and 5000 magnifications. When the images of the samples are examined; it can be seen that non-absorbed paste and dyestuff are found on the surface of the samples fixed for 6 minutes. However, sample surfaces fixed for 10 minutes appear smoother. The reason for this was interpreted as more binding to the fibre.

Table 8

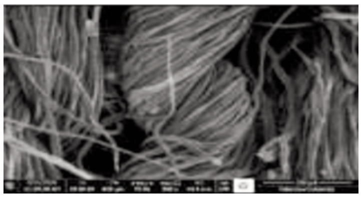
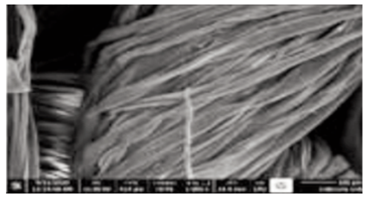
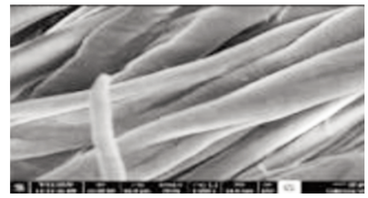
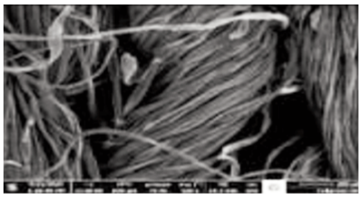
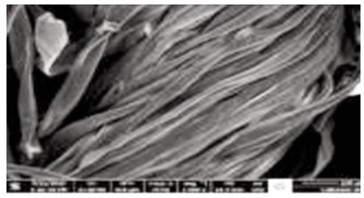
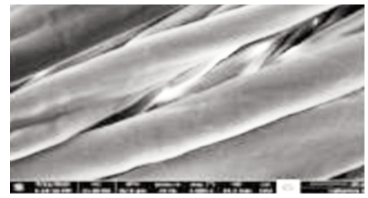
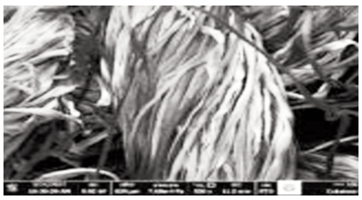
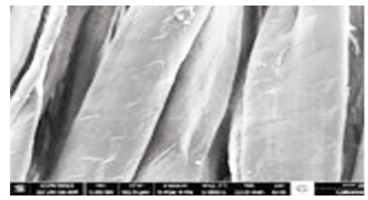
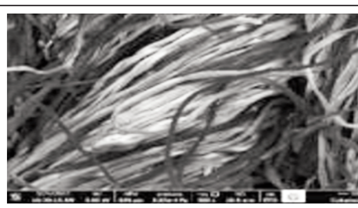
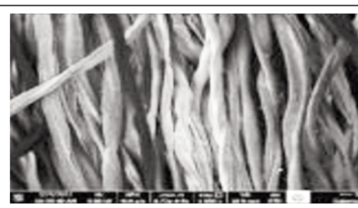
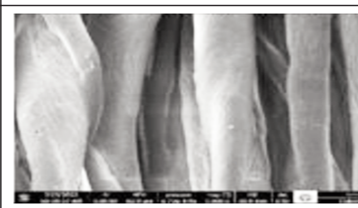
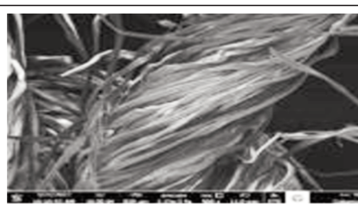
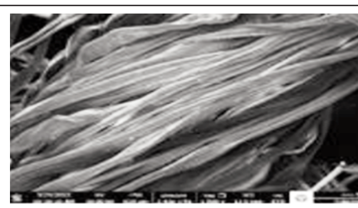
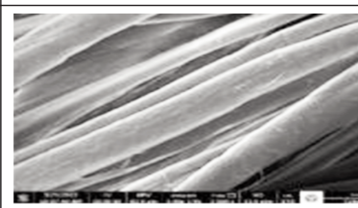
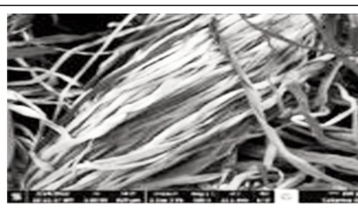
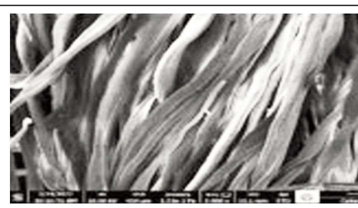
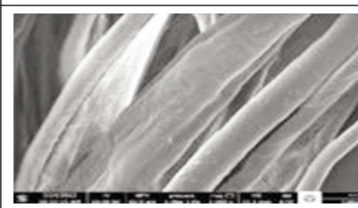
For PK-P12	**Air permeability**	**Bursting Strength**	**Stiffness**
Material	0.000	0.794	0.000
Fixing Time	0.000	0.664	0.149
P30	**Air permeability**	**Bursting Strength**	**Stiffness**
Fixing Time	0.000	0.003	0.873

CONCLUSIONS

In today's world, where sensitivity to the environment touches all production and consumption stages, many studies are carried out within the scope of sustainability. In the study, a digital printing application, which is an environmentally friendly colouring method, was carried out by using hemp, which is one of the sustainable fibres.

According to the research, it was seen that the fabric thickness and weight of the samples increased as the yarn thickness increased. It is seen that heavier fabric will have higher stiffness. Also, thicker yarns have higher bursting strength. It follows that because of

Table 9

SEM ANALYSES				
		500×	**1000×**	**5000×**
P30/1	**6 min.**			
	10 min.			
P12/1	**6 min.**			
	10 min.			
PK	**6 min.**			
	10 min.			

the cotton-hemp blended fibres (PK) have high unevenness, the bursting strength of the fabrics produced from this raw material is lower than cotton fabrics (P12). Similarly, since the thin-thick place values of cotton-hemp blended yarns are high, this porous structure also increases the air permeability of the fabrics.

When the results are evaluated, the effects of these parameters can be analysed by conducting more comprehensive studies on the fixation time and raw material.

ACKNOWLEDGEMENTS

This study is a doctoral thesis carried out with the project titled FDK-2018-11302 'Investigation of Garment Comfort Properties of Knitted Fabrics from Different Raw Materials Applied with Digital Printing' and it is supported by Çukurova University Scientific Research Projects Unit.

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