Serin Mezarcıöz

Çukurova University,
Faculty of Engineering,
Department of Textile Engineering,
Adana, Turkey,
* e-mail: smavruz@cu.edu.tr

Effect of Industrial Washing and Laundering on the Colour Values of Knitted Denim

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Abstract

One of the most distinctive features of denim is that the warp yarn is dyed with indigo dye and the weft yarns are not dyed, i.e. white. Although warp yarns dyed with indigo dye are woven with different woven fabric weaves, classical denim fabrics weave are produced with 3/1 Z twill weave. The search for new products in denim has led businesses to produce denim-looking knitted fabrics. Denim-looking knitted garments are subjected to industrial washing at the production phase and repetitive household washing processes in daily life. Repeated washing and drying processes cause changes that can affect user satisfaction in terms of losing the colour of the fabric. Therefore, in this study, the colour values of knitted denim fabrics produced as an alternative to denim fabrics manufactured by traditional methods after various industrial (rinse, enzyme and stone washing) and home washes (5, 10, 20 times) were examined. For this, the CIELab colour system was taken as the basis for colour analysis on a spectrophotometer device. As a result of the washing processes performed on each fabric sample (household washing and rinse, enzyme, stone washing applications), it was observed that there were differences in colour values depending on the fibre type, loop yarn length, fabric construction and washing process.

Key words: *indigo, knitted denim fabric, colour, spectrophotometric analysis.*

Introduction

Denim clothing is one of the most important branches of the woven garment industry in Turkey. When Turkey's export report of January 2020 in analysed, it is seen that Turkey's denim fabric exports had increased by 32,8% and reached 28 million dollars [1]. Denim fabric is a woven fabric in which the inner texture is white and the outer indigo dyed. Indigo is a dye generally used in denim fabrics.

The aged look, created by abrasion, is the most important feature of denim fabrics. As the abrasion begins, the whiteness in the inner layer emerges and a worn-out appearance is created. Since the warp yarns are dense on the surface of denim fabric in terms of both the weaving requirement and density, the colour of the warp yarn dominates the fabric appearance. Denim producers can manufacture it with different raw materials as weft yarn while using cotton yarn as warp yarn. Although the performance characteristics of denim are very effective in the changing and developing fashion industry, features such as colour, appearance and touch are attractive to the consumer. This situation has brought businesses to seek to produce fabrics with a new look and different touch. This curiosity has brought about the idea of indigo dyed knitted fabric.

Knitted denim fabrics are produced on a knitting machine with the use of indigo and white colour yarns separately in the same fleecy fabric. The diagonal fleecy pattern and indigo colour of the face yarn give a denim appearance to the knitted fabric [2]. Knitted denim fabric, with its delicate structure, clear lines, softness and breathable comfort, offers the ultimate solution of creating a balance between fashion and comfort. Knitted denim is also available in attractive indigo blue shades and is made for a variety of applications and in a wide range of quality and shades, the most popular being black denim. This denim is comfortable, fashionable, affordable, durable and popular with all age groups [3].

Producing denim-like knitted fabric has been popular for years, but there are limited researches about their properties.

Gokernasan et al. tried to find a knitted fabric type resembling woven denim fabric in terms of appearance and performance properties. Therefore, they manufactured knitted fabrics with different patterns and properties. They showed that diagonal two-fleece patterned fabric was the most convenient one [4]. Degirmenci and Celik investigated the dimensional stability of denim-like knitted fabrics and reported that fleecy yarn raw material effected a change in the dimensional behaviour of the sample knitted fabrics. Therefore, to produce denim-like knitted fabrics; selecting grey polyester as fleecy yarn and indigo dyed cotton as face yarn gives the most convenient result [5]. The strength and elasticity of denim-like knitted fabrics were also researched by Degirmenci and Çelik, who explained that using elastomeric yarn with the face yarn makes the fabric elastic and strong. Denim-like knitted fabrics are convenient to produce jeggings as their resistance to bursting increases with the use of synthetic yarns, such as fleecy yarn [6].

Table 1. Quality parameters of the yarns used in denim knitted fabrics

Yarns	Breaking strength, cN/tex	Elongation at break, %	Unevenness, %U	Hairiness	Thin places, -50%	Thick places, +50%	Neps, +280%
Face yarn cotton-Ne 30	19,95	6,27	9,23	3,66	0,0	21,7	8,3
Fleecy yarn cotton-Ne 30	20,03	3,90	8,73	4,18	0,0	10,5	6,7
Fleecy yarn modal-Ne 30	17,84	5,42	9,73	5,79	0,8	31,7	15,8
Fleecy yarn viscose-Ne 30	17,58	13,57	9,89	3,88	2,5	17,5	4,2

Table 2. Machine parameters.

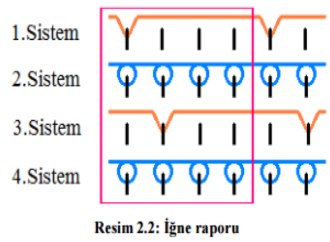
Brand	Pirotelli
Cylinder diameter	32"
Needle gauge	28
Number of feeder	96
Number of needle	2760
Loop length	Slack: 0.33 mm face side-0.11 mm reverse side Medium: 0.30 mm face side-0.11 mm reverse side Tight: 0.27 mm face side-0.11 mm reverse side
Needle diagram	

Table 3. Specifications of the denim knitted fabrics

Abbreviation	Type	Tightness	Courses per cm	Wales per cm	Loop shape factor	Loop density	Weight g/m²
1CC		tight	20	12	1.7	240	181.5
2CC	cotton-cotton	medium	18	12	1.5	216	179.0
3CC		slack	15	11	1.4	165	177.5
4CV		tight	19	11	1.7	209	172.3
5CV	cotton-viscose	medium	18	11	1.6	198	170.0
6CV		slack	15	12	1.2	180	167.9
7CM		tight	20	12	1.7	240	185
8CM	cotton-modal	medium	17	12	1.4	204	183.2
9CM		slack	16	12	1.3	192	179.1

Research was carried out by Didar et al. using a single jersey circular knitting machine to create the denim effect with knit and tuck loops separately. The spirality, weight, shrinkage, bursting strength and air permeability properties of the knitted denim versus woven denim fabrics were evaluated [3].

Nowadays, with the development of washing processes and chemical features used, various types of washing processes are applied to denim fabrics. Accordingly, through the conditions of use of consumers, it took on its own colour and abrasion effects over time. However, this process takes a long period of time, and denim manufacturers developed different methods to make the process shorter. These washing methods were rinse, enzyme, stone wash, stone+bleach, etc.) [7].

Studies on the effect of the washing process on denim fabrics can be summarised as follows. Denim fabrics made of 100% cotton yarn and dyed with indigo dyestuff were subjected to different washing process (rinse, stone, hypo, etc.), and changes in the tearing strength and tensile strength were investigated by Cetinaslan et al. [8]. The strength values of denim fabrics with three selected weights were compared. The strength values of the denim fabrics were decreased after the washing process. Mezarcioz and Toksöz investigated the effect of the woven structure and washing processes on denim fabric's performance properties, like dimensional stability, breaking strength, tearing strength, bending rigidity, surface view examination and colourimetric evaluation [9]. Eight different washing treatments were applied to denim-like knitted fabrics and studied by Değirmenci (2017). The bursting strength test was applied to the samples obtained and their strength losses calculated. At the end of the study, the most suitable washing treatment for denim-like knitted fabrics was selected [2]. Khan and Mondal; manufactured 3/1 twill indigo dyed woven denim fabrics and exposed them to standard enzyme washing treatment changing only the processing time. Then they measured the performance properties of the samples. Results showed that the tensile strength, stiffness and colour shade decrease after the cellulase enzyme washing treatment [10]. Sarkar and Khalil produced cotton 3/1 twill warp faced indigo dyed denim fabrics, applying a standard desizing recipe, as well as bleaching and neutralizing processes. The process was then completed by softening, and the effects of washing on performance were examined. Bleaching and softening treatment have a great influence on the mechanical and colour properties of denim fabrics [11].

According to the literature, no study has been done that systematically examines the effects of industrial and repeated household washing on the colour values of knitted denim fabrics. The lack of this information about denim knitted fabrics in the literature will be filled by this study. For this reason, 9 denim knitted fabrics were produced with 3 different loop densities, consisting of face yarn of cotton, fleecy yarn of cotton, viscose and modal fibres. Colour values (L*, a*, b* C* and h) of these fabrics were measured after standard finishing processes by employing the CIELab system. And the effect of the loop length and fibre type on colour values was assessed using graphs and statistical analysis. The tightest knitted fabrics from each fibre type were selected and rinse, enzyme and stone washing processes were applied in order to determine the effect of industrial washing. In order to determine the effect of repeated home washing on the colour of the fabrics, the tighttness of fabrics after rinse washing, which is the industrial washing process most applied for denim fabrics, were selected. 5, 10 and 20 home washes were applied to these fabrics and their colour values examined. Colour measurement results were evaluated in relation to both fleecy yarn raw material and the washing treatments applied (industrial and home laundering). To control the significance of dependent variables for the colour values of the samples, ANOVA analyses were performed using the SPSS 22.0 statistical programme.

Material and method

The face yarn of all the samples was of the Ne 30/1 100 % cotton ring spun type. The counts of the fleecy yarns were Ne 30/1. Face yarns were dyed by the rope dyeing method in a mill. The raw materials of the fleecy yarns varied as cotton, modal or viscose, which were also ring spun yarns. Quality tests of the yarns mentioned were carried out on Uster Tester 5-S800 and Uster Tensojet 4 test devices (***Table 1***).

In this study 9 knitted denim fabrics were produced with a flat knitting machine according to the parameters in ***Table 2***. An image of the knitted fabric and the needle diagram are also presented in ***Table 2***. Three levels of loop length were selected: 0.27, 0.30 and 0.33 mm, which represent tight, medium and slack fabrics. Properties of the denim knitted fabrics are shown in ***Table 3***.

The denim knitted fabrics were subjected to pretreatment and finishing processes. The commercial wet process was applied to all the fabrics in the textile factory (***Table 4***).

After the wet process, the colour values of the fabrics were measured, and the effect of the fibre type and loop yarn length on the colour values of the denim knitted fabrics was determined.

In order to determine the effect of industrial and household washing on the colour values of denim knitted fabrics, fabrics numbered 1, 3 and 7 were chosen (tightest fabric at each mixture ratio). It was attempted to determine the effect of industrial washing processes on the colour of denim knitted fabrics by applying rinse, enzyme and stone washing processes to these fabrics. In order to determine the effect of repeated home washing on the colour of the fabrics, the tightest ones after rinse washing, which is the industrial washing process most applied for denim

Table 4. *Wet process applied.*

Action	Content and conditions
Singeing	Machine speed:35 m/min, temperature 90 °C, both sides singeing
Washing	Time: 20 minutes, heat: 90 °C, bath ratio l:30
Drying	at 60 °C for 2 h
Finishing	40 gr/lt hydrophilic silicone 40gr/lt fixator 2 gr/lt wetting agent 1 gr/lt acid pH: 5
Fixing	temperature 140 °C, 1 minute

Table 5. *Descriptions of denim industrial washing techniques.*

Process	Step name	Step details				
		Time, min.	Temperature, °C	Chemical name	Manufactures	Quantity
Rinse washing	Softening	2	30	Belfasin EG	Pulcra chemicals	3 ml/lt
				Adasil SM		3 ml/lt
	Drying	45	80			
Enzyme washing	Enzyme washing	30	45	Enpilase	Enkim	0,8 %
	Drying	30	40			
Stone washing	Stone washing	30	45	ATB 96L	Garmen chemicals	3 ml/lt
				Lava Sperse KKC	DyStar	2 ml/lt
	Softening	10	40	Belfasin EG	Pulcra chemicals	3 ml/lt
				Adasil SM		3 ml/lt
	Drying	45	80			

Table 6. *Effect of fibre type and loop length on the colour values of denim knitted fabrics.*

Factor	Dependent variable	F	Sig.	Factor	Dependent variable	F	Sig.
Fibre type	L*	5.132	.05*	**Loop length**	L*	1.465	.303
	a*	1.394	.318		a*	.814	.487
	b*	9.381	.014*		b*	.456	.654
	C*	9.492	.014*		C*	.794	.495
	h	.456	.654		h	2.102	.203

fabrics, were selected. 5, 10 and 20 home washes were applied to those fabrics and their colour values examined. Industrial washing processes applied in this study to knitted fabrics made of indigo dyed yarn are given in ***Table 5***.

Colour measurements

Colour measurements of the selected samples were performed by employing the CIELab system, with a 10° standard observer and under D65 daylight. And L*, a*, b*, C* & h values were recorded. In the study a Minolta CM 3600 D spectrophotometer was employed. Real Color 1.3® software was used to calculate the colour difference values [12]. The CIELAB coordinates (L*, a*, b*, C*, h), and colour difference (ΔE*) values were measured as colour values. The L* value represents lightness and varies from 0 (black) to 100 (white). The a* and b* values refer to redness-greenness and yellowness-blueness, respectively. The chroma, C*, measures colour saturation. The hue angle, h, ranging between 0° and 360°, measures the colour range, and the angles of 0°, 90°, 180° and 270° refer to red, yellow, green and blue shades, respectively [13]. Unwashed fabric (for each type of fabric) was accepted as reference when calculating the colour differences (ΔE*). ΔE* was obtained according to the CIEL*a*b* equation (1976). There is no international standard for the total colour difference. This value was determined with respect to quality standards of the manufacturer and customer demands. In this experimental study, the total colour difference tolerance was assumed as 1,0.

Before measurement, the fabrics were conditioned for 24 hours in a standard atmosphere of 20 ± 2 °C temperature and 65 ± 2%. relative humidity. 3 measurements were made for each sample. All statistical analyses were made using the SPSS program. Analysis of variance

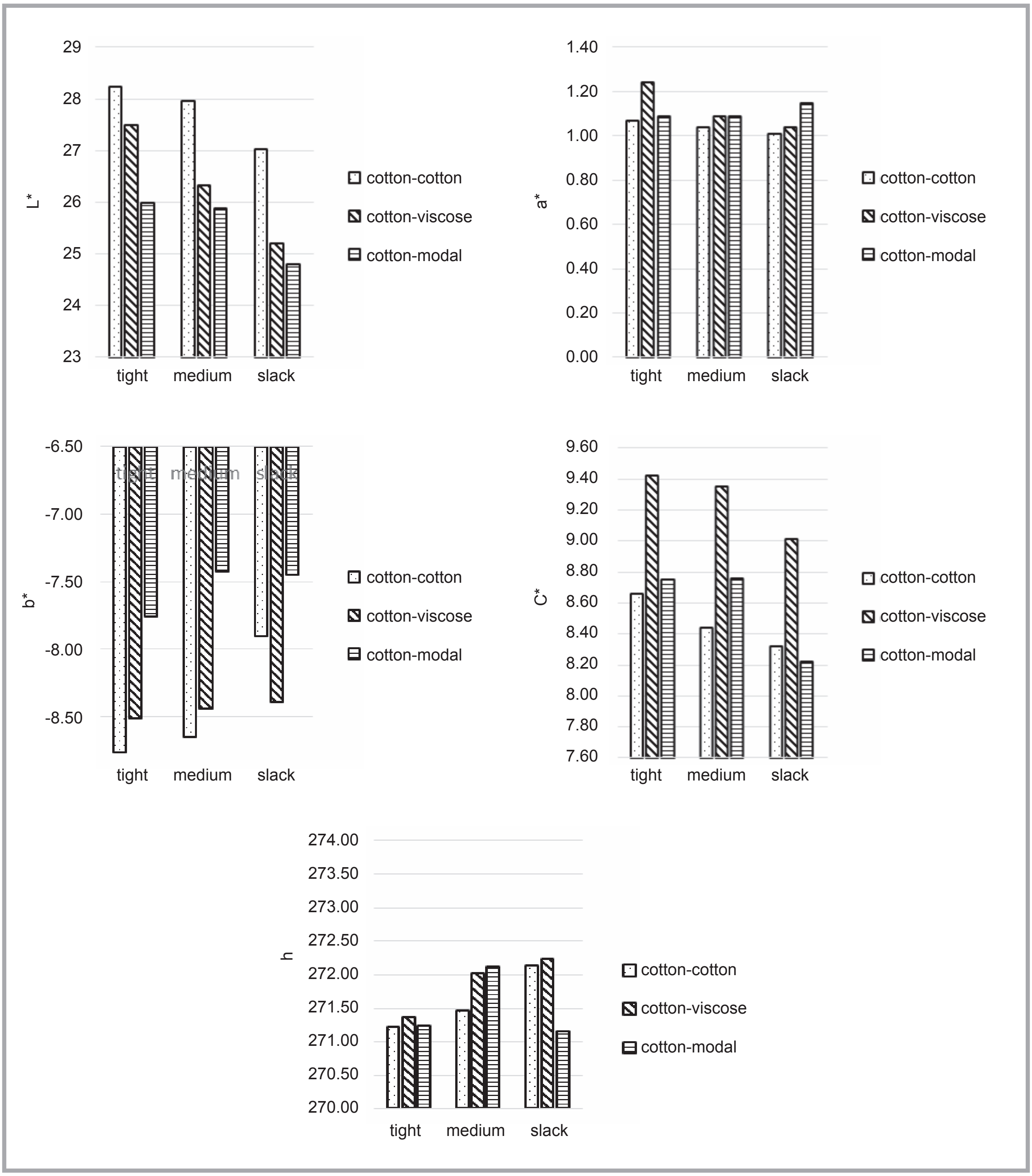


Figure 1. *CIELab values of fabrics.*

(ANOVA) was applied to understand the effects of the fibre type, loop length and washing treatments (industrial and home laundering) on the values studied. Comparisons were made among the groups for the fibre type, loop length and washing treatments (industrial and home laundering) using the post-hoc LSD procedure. All the results were assessed at the 0.05 level of significance [14].

Results and discussion

Effect of fibre type and loop length on colour values

In order to determine the effect of fibre type and loop length on the colour values of denim knitted fabrics, which was the first step of the study, colour values of the fabrics given in ***Table 3*** were measured. In ***Figure 1***, the measurement results (L*, a*, b*, c* and h) are graphically given. In order to evaluate the effect of fibre type and loop length on the colour values of denim knitted fabrics, analysis of variance was done at the $\alpha = 0,05$ significance level via the SPSS statistical package program (***Table 6***). Furthermore, multiple comparison tests were performed according to the LSD method (***Table 7***).

According to ***Figure 1***, for L* values, cotton/cotton fabrics for all loop lengths have the highest L* values, which means that the colours of cotton-cotton are the lightest. It is seen that cotton-modal fibres have the smallest L* values. However, the effect of the loop length on colour values is found to be statistically insignificant; as the loop length increases (as the fabric becomes sparse), L* values decrease, i.e. the colour of the fabrics becomes darker. As the fabric structure loosens, as stated by Demiröz Gün and Tiber (2011), the penetration of dye into the fabric may become easy, and a darker colour is obtained. The fact that cotton-cotton fabrics have the highest L* values can be explained by the amorphous region/crystalline region ratio of cotton fibres. While the ratio of the crystalline region to the amorphous region is 70/30 in natural cellulose fibres, this ratio is 35/65 in regenerated cellulose fibres. Since chemicals and dyes can only enter amorphous regions, regenerated cellulose fibres are more affected by chemical substances [15]. Thus, cotton-viscose and cotton-modal fibres become darker.

According to ***Table 6***; fibre type is statistically significant for L* values. No significant difference was found between cotton-viscose and cotton-modal values according to the multiple comparison test performed using the LSD method. Also, when ***Figure 2*** is examined, cotton-viscose and cotton-modal fibres are generally close to each other for all colour values. As Demiröz Gün and Tiber stated in 2011, since viscose and modal have the same chemical composition, their ability to incorporate dyes into the structure is also similar.

The fibre type and loop length did not have a statistically significant effect on the a* and h values of the fabrics. The fact that the hue angle (h) values are between 271,14-272,22 indicates that the fabrics correspond to the blue region in the hue circle. Cotton-cotton samples have the lowest b* value. The difference between b* values of the cotton-cotton and cotton-modal samples was statistically insignificant. For all fabrics, it can be said that as the loop length increases, the L* and C* values decrease, that is, the colour of the fabrics gets darker and deeper.

Effect of industrial washing on colour values

Nowadays, with the development of washing processes and chemicals fea-

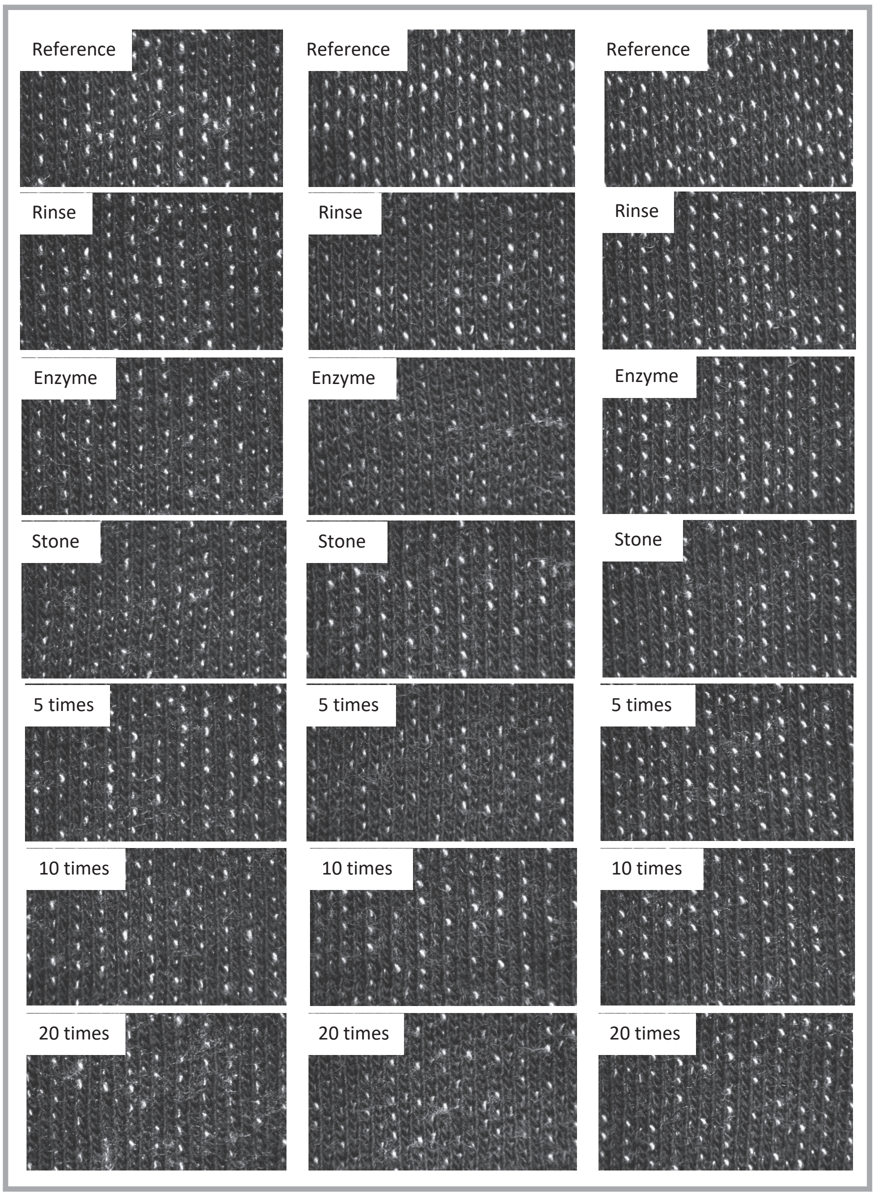


Figure 2. *Images of samples after industrial and home laundering (magnification 8x).*

Table 7. *Multiple comparison test results between fibre types.*

Dependent variable	I (fibre type)	J (fibre type)	Mean difference (I-J)	Sig.
L*	cotton-cotton	cotton-viscose	1.40000	.089
		cotton-modal	2.18000	.020*
	cotton-viscose	cotton-cotton	-1.40000	.089
		cotton-modal	.78000	.301
	cotton-modal	cotton-cotton	2.18000	.020*
		cotton-viscose	–.78000	.301
b*	cotton-cotton	cotton-viscose	.01000	.968
		cotton-modal	–.89333	.010*
	cotton-viscose	cotton-cotton	–.01000	.968
		cotton-modal	–.90333	.009*
	cotton-modal	cotton-cotton	.89333	.010*
		cotton-viscose	.90333	.009*
C*	cotton-cotton	cotton-viscose	–.78667	.007*
		cotton-modal	–.10333	.617
	cotton-viscose	cotton-cotton	.78667	.007*
		cotton-modal	.68333	.013*
	cotton-modal	cotton-cotton	.10333	.617
		cotton-viscose	–.68333	.013*

Table 8. *Colour differences for industrial washed samples.* ***Note:*** *ΔL* = Difference in lightness/darkness value, ΔC = Difference in chroma, Δa* = Difference on red/green axis, Δb* = Difference on yellow/blue axis, Δh* = Difference in hue, ΔE = Total colour difference value.*

Sample number	ΔL*	Δa*	Δb*	ΔC*	Δh*	ΔE
1CC-R	-3.37	0.26	-0.94	0.97	0.14	3.51
1CC-E	-3.01	-0.64	-2.47	2.41	-0.83	3.95
1CC-S	-2.61	-0.45	-1.78	1.73	-0.60	3.19
4CV-R	-1.84	-0.03	-0.62	0.61	-0.18	1.94
4CV-E	-1.35	-0.71	-2.03	1.94	-1.37	2.54
4CV-S	-1.26	-1.10	-2.41	2.29	-1.94	2.93
7CM-R	-1.90	0.01	-1.19	1.18	-0.12	2.24
7CM-E	-1.40	-0.52	-1.94	1.90	-0.68	2.45
7CM-S	-2.86	-0.71	-2.40	2.35	-0.88	3.80

Table 9. *Effect of industrial washing type on colour values.*

Factor	Dependent variable	F	Sig.
Industrial washing	ΔL*	.203	.821
	Δa*	12.833	.007*
	Δb*	16.184	.004*
	Δc*	14.991	.005*
	Δh*	4.624	.061
	ΔE	.780	.500

Table 10. *Multiple comparison of test results between industrial washing types.*

Dependent variable	I (Industrial washing)	J (Industrial washing)	Mean difference (I-J)	Sig.
Δa*	Rinse	Enzyme Stone	.70333* .83333*	.007* .003*
	Enzyme	Rinse Stone	–.70333* .13000	.007* .490
	Stone	Rinse Enzyme	–.83333* –.13000	.003* .490
Δb*	Rinse	Enzyme Stone	1.23000* 1.28000*	.003* .002*
	Enzyme	Rinse Stone	-1.23000* .05000	.003* .851
	Stone	Rinse Enzyme	-1.28000* –.05000	.002* .851
Δc*	Rinse	Enzyme Stone	-1.16333* -1.20333*	.003* .003*
	Enzyme	Rinse Stone	1.16333* –.04000	.003* .878
	Stone	Rinse Enzyme	1.20333* .04000	.003* .878

Table 11. *Colour differences after repeated home laundering for rinse washed samples.* ***Note:*** *ΔL* = Difference in lightness/darkness value, ΔC = Difference in chroma, Δa* = Difference on red/green axis, Δb* = Difference on yellow/blue axis, Δh* = Difference in hue, ΔE = Total colour difference value.*

Sample number	ΔL*	Δa*	Δb*	ΔC*	Δh*	ΔE
1CC-R-5	-3,09	-0,15	-1,90	1,88	-0,34	3,63
1CC-R-10	-2,81	-0,32	-2,31	2,27	-0,53	3,65
1CC-R-20	-1,27	-0,53	-2,46	2,41	-0,73	2,82
4CV-R-5	-0,64	-0,61	-1,42	1,34	-1,14	1,67
4CV-R-10	-0,63	-0,75	-1,97	1,88	-1,42	2,20
4CV-R-20	-0,66	-0,83	-1,95	1,85	-1,52	2,22
7CM-R-5	-3,25	-0,26	-2,29	2,25	-0,47	3,98
7CM-R-10	-2,83	-0,38	-2,74	2,69	-0,62	3,95
7CM-R-20	-2,17	-0,45	-3,08	3,03	-0,70	3,79

tures used, various types of washing processes are applied to denim fabrics. In this study, 3 different types of industrial washing processes (rinse, enzyme and stone) were applied to denim knitted fabrics 1, 4 & 7 . Details of the process are given in ***Table 5*** above.

In order to see the effect of the industrial washing process, total colour difference values were examined. Colour values of all samples are presented in ***Table 8***. (For example; the 1CC-R sample represents a tight cotton-cotton sample treated with enzyme rinsing). Δ values of the washed samples were determined by referencing unwashed (original) samples.

The effects of industrial washing type on all the colour values were analysed using ANOVA analysis, followed by LSD statistical test methods, given in ***Table 9*** and ***Table 10***. The ANOVA analysis results indicate that the effects of the industrial washing type on Δa*, Δb* & Δc* colorimetric values are highly significant.

According to ***Table 8,*** the biggest colour difference was seen in cotton-cotton samples as a result of rinse, enzyme and stone washing. It was observed that enzyme and stone washes cause the biggest colour change. According to the results of the multiple comparison tests given in ***Table 10***, the difference between rinse washing and the other two washes is significant, and that between enzyme and stone washes not statistically significant. Since rinse washes are soft washes performed with softener, they do not cause much change in both the appearance and performance properties of the product as much as enzyme and stone washes. The enzyme used in enzyme washing and pumice stones used in stone washing can cause deformation in the fabric. Therefore; it is estimated that the colour difference between enzyme and stone washes is not significant, but that between rinse washing and the other two washes is .

Effect of repeated laundering on colour values

The purpose of this part was to investigate the effects of repeated laundering on the denim knitted fabrics.

In order to determine the effect of repeated home washing on the colour of the fabrics, the tightest fabrics after rinse washing, which is the industrial washing process most applied for denim fabrics, were selected. 5, 10 and 20 home washes were applied to those fabrics and their colour values examined. Results are shown in ***Table 11***. (For example; the 1CC-R-5 sample is a tight cotton-cotton fabric rinsed washed 5 times repeatedly). Δ values of the washed samples were determined by referencing unwashed (original) samples.

According to ***Table 11***, the biggest colour change was detected in cotton-cotton and cotton-modal samples. Although it was found statistically that the number of repetitive washes did not have a significant effect on the colour values of the fabrics (***Table 12***), it can be said that the more the number of washes for almost all samples, the lighter the colour. Images obtained of the samples after industrial washing and of the fabrics after repeated washing are given in ***Figure 2***. As can be seen, the images of the samples washed compared with the unwashed sample are very close to each other.

Conclusions

This study aimed to analyse the effect of fibre type, loop length, industrial washing and repeated home laundering on the colour values of denim-knitted fabrics.

As a result of the study, the following data were obtained.

Cotton/cotton fabrics for all loop lengths have the highest L* values. Although the effect of loop length on the fabrics' L* values is not statistically significant, it is seen that the L* values decrease as the fabric structure gets thinner, in other words, the fabrics become darker. Cotton-modal fibres were found to have the smallest L* values, which can be explained by the ratio of crystalline region/amorphous region that the fibres have. Chemicals and dyes can only enter amorphous regions; regenerated cellulose fibres are more affected by chemical substances. Since viscose and modal fibres have the same chemical composition, generally all colour values are close to each other.

It was observed that industrial washings have a significant effect on the Δa*, Δb* & ΔC* values of the fabrics, with enzyme and stone washings have the greatest effect. There were no significant differences between ΔL* values, and when looking at the images obtained of the fabrics after industrial and repeated washing, it can be seen that there are no significant changes in the colour values of the samples. It is thought that denim knitted fabrics can protect their colour values against industrial washing.

Table 12. *Effect of repeated laundering on colour values.*

Factor	Dependent variable	F	Sig.
Repeated laundering, times	ΔL*	.522	.618
	Δa*	1.029	.413
	Δb*	1.452	.306
	Δc*	1.245	.353
	Δh*	.398	.688
	ΔE	.077	.927

When the effects of repeated washings on the colour values of the samples were examined, they were found statistically insignificant. When the related table is observed, it is seen that there are the biggest ΔL* changes after the 5th wash in general, and there is no significant change in this value after the 10th and 20th washes.

Detergent and mechanical effects remained negligible with increasing washing cycles. The biggest colour difference was seen in cotton-modal samples. Modal fibres are expected to be more resistant to alkalis, especially when compared to viscose; in this study, it was seen that they were greatly affected by detergent. This may also be due to the nature of the detergent.

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