LAUNDERING-INDUCED ALTERATIONS IN COLOR AND WHITENESS OF COTTON-BASED FABRICS: A COMPARATIVE ANALYSIS OF POWDER AND LIQUID DETERGENTS

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Abstract: *Maintaining the intrinsic chromatic integrity of dyed textiles is paramount for optimizing product lifecycle value, enhancing consumer perception, and advancing sustainable material stewardship. This study presents a rigorous quantitative analysis of colorfastness degradation in representative light and dark dyed cotton and cotton/polyester blend fabrics subjected to 25 cycles of accelerated laundering using leading commercial powder and liquid detergent systems. Comprehensive spectrophotometric and colorimetric characterization, including CIELab coordinates, K/S values, and total color difference (ΔE*), reveals significant performance differentials. Data demonstrate that powder detergent formulations, often incorporating potent oxidative chemicals, induce substantial dye degradation and accelerated chromatic shift across test substrates. Conversely, liquid detergent variants, typically engineered without aggressive bleaching components, exhibit superior color preservation capabilities, yielding statistically significant lower ΔE* values. These findings underscore a critical design challenge at the intersection of cleaning efficacy and material durability – a direct trade-off between chemical intensity and sustained aesthetic quality. The insights derived from this investigation are crucial for the strategic development of next-generation, high-performance, and eco-optimized laundering technologies that deliver enhanced fabric care, extend product aesthetic life, and enable differentiated market positioning aligned with increasingly discerning, sustainability-aware consumer demands.*

Keywords: textile laundering, color fastness, detergent formulation, CIELab color coordinates, whiteness index, sustainable fabric care.

PROMENE U BOJI I BELINI PAMUČNIH TKANINA IZAZVANE PRANJEM: UPOREDNA ANALIZA PRAŠKASTIH I TEČNIH DETERDŽENATA

Apstrakt: *Održavanje inherentnog hromatskog integriteta bojenih tekstila je od primarnog značaja za optimizaciju vrednosti životnog ciklusa proizvoda, unapređenje percepcije potrošača i razvoj održivog upravljanja materijalima. Ova studija predstavlja rigoroznu kvantitativnu analizu degradacije postojanosti boje na reprezentativnim svetlim i tamnim bojenim tkaninama od pamuka i mešavine pamuka/poliestera, podvrgnutih 25 ciklusa ubrzanog pranja korišćenjem vodećih komercijalnih praškastih i tečnih deterdžentskih sistema. Sveobuhvatna spektrofotometrijska i kolorimetrijska karakterizacija, uključujući CIELab koordinate, K/S vrednosti i ukupnu razliku u boji (ΔE), otkriva značajne razlike u performansama. Podaci pokazuju da formulacije praškastih deterdžena-*

ta, često uključujući potentne oksidativne hemikalije, indukuju značajnu degradaciju boje i ubrzano hromatsko pomeranje na testiranim supstratima. Nasuprot tome, varijante tečnih deterdženata, tipično projektovane bez agresivnih komponenata za izbeljivanje, pokazuju superiorne sposobnosti očuvanja boje, dajući statistički značajno niže ΔE vrednosti. Ovi nalazi naglašavaju kritičan izazov u dizajnu na preseku efikasnosti čišćenja i trajnosti materijala – direktan kompromis između hemijskog intenziteta i održanog estetskog kvaliteta. Uvidi proistekli iz ovog istraživanja ključni su za strateški razvoj sledeće generacije visokoefikasnih i ekološki optimizovanih tehnologija pranja koje pružaju poboljšanu negu tkanina, produžavaju estetski vek proizvoda i omogućavaju diferencirano pozicioniranje na tržištu usklađeno sa sve zahtevnijim potrošačima svesnim održivosti.

Ključne reči: pranje tekstila, postojanost boje, formulacija deterdženata, CIELab kolor koordinate, indeks beline, održavanje tkanina na održiv način.

1. INTRODUCTION

In modern textile consumption, garment quality is increasingly evaluated not just through aesthetics and comfort, but also through durability, ease of care, and environmental impact. Among these attributes, color retention has emerged as a top priority for consumers, frequently influencing purchase decisions more than fabric type, tactile properties, or price [1]. Maintaining the original color appearance of a fabric throughout its lifecycle is widely regarded as a key indicator of both product value and consumer satisfaction. However, color degradation during laundering remains a significant challenge in the textile industry, often contributing to premature disposal, higher replacement rates, and increased environmental burden. Textile garment-whether dyed in solid shades or patterned through printing techniques such as pigment, reactive, or sublimation printing-are particularly vulnerable to color loss when exposed to repeated washing [2-4]. Ensuring long-term color stability in these products is therefore essential not only for consumer satisfaction but also for extending garment lifespan and reducing environmental impact.

As the most frequent and aggressive maintenance process, laundering is responsible for cumulative mechanical, thermal, and chemical stresses that directly affect fabric aesthetics and integrity. Color fading, dye bleeding, and loss of whiteness are common phenomena resulting from washing, leading to visual deterioration and decreased garment appeal over time [5-9]. These changes not only impact consumer perception but also have broader implications for textile sustainability, particularly in the context of extending product life cycles and reducing textile waste. According to the Sinner Circle model, laundering efficacy and its impact on textiles depend on the interplay of four key parameters: temperature, time, mechanical agitation, and chemical action [10]. Adjustments in one component (e.g., lowering temperature to save energy) necessitate compensatory changes in others (e.g., stronger chemical detergents or longer wash cycles) to maintain performance without compromising fabric quality [11].

Among these parameters, the detergent formulation plays a central role in both cleaning efficiency and fabric preservation [12]. Commercial detergents are sophisticated chemical systems composed of surfactants, enzymes, builders, bleaching agents, optical brighteners, complexing agents, and other additives [13]. These formulations are engineered to perform a variety of tasks—soil removal, stain dispersion, odor control, and brightness enhancement-while attempting to minimize damage to the fabric. Two of the most widely used detergent forms, powders and liquids, account for the majority of global market share [14]. However, they differ markedly in composition and behavior during the wash process [13,15-17].

Powder detergents often contain activated oxygen bleach and optical brighteners designed to enhance the whiteness of light fabrics. While effective in removing stains and improving brightness, these ingredients are also associated with oxidative degradation of dyes, particularly in dark or brightly colored garments [18,19]. On the other hand, liquid detergents typically omit bleaching agents and brighteners, relying instead on surfactant-rich formulas that offer gentler treatment for dyed fabrics. Although they may be less effective at whiteness enhancement, liquid detergents are often favored for preserving color fidelity and reducing fabric wear, particularly under lower-temperature washing conditions.

This divergence in formulation and functionality has significant implications for sustainable garment care. Frequent color degradation leads to faster disposal and replacement, contributing to the environmental footprint of the textile sector. As both consumers and industries move toward more sustainable product lifecycles, understanding how detergent type affects fabric appearance over time becomes critical [14]. Insight into how different detergents impact both whiteness in light-colored fabrics and colorfastness in dyed fabrics can guide more sustainable consumer habits and support the development of next-generation textile care products.

Despite the increasing availability of commercial detergent products and rising attention to sustainable laundering, few studies have systematically examined the comparative impact of powder and liquid detergents on both white and colored fabrics across multiple wash cycles, especially in commonly used fiber compositions such as cotton and cotton/polyester blends. Previous work has focused primarily on soil removal, energy savings, or microbiological hygiene, with limited attention to long-term optical property retention in textiles [14,19-21].

The objective of this study is to bridge that gap by evaluating the laundering-induced changes in color strength and whiteness index of cotton-based fabrics subjected to 25 domestic wash cycles using commercial powder and liquid detergents. Colored fabrics are assessed through CIE L*a*b** color coordinates, color strength (K/S), and color difference while white fabrics are analyzed using whiteness index measurements. The results provide quantitative insights into the durability of optical properties under repeated laundering and offer practical recommendations for detergent selection, fabric engineering, and sustainable garment care strategies.

2. EXPERIMENTAL PART

2.1 Materials

The whiteness index, CIE L*, a*, b* color coordinates, and color strength (K/S) of the control white and dyed woven fabrics composed of 100% cotton and cotton/polyester blends are presented in Table 1.

2.2 Laundering procedure

White and colored fabric samples were subjected to 25 laundering cycles following the ISO 6330:2010 standard. Laundering was performed at 60 °C for white and light-colored fabrics, and at 40 °C for dark-colored fabrics. Each fabric was washed separately using either a powder detergent (PD) or a liquid detergent (LD). According to the manufacturer's specifications, the powder detergent contained 5–15% anionic and 5% nonionic surfactants, along with soap, phosphates, zeolites, enzymes, polycarbonates, bleaching agents, optical brighteners, and fragrances. The liquid detergent formulation included 15–30% anionic surfactants, benzyl benzoate, 2-(4-tert-butylbenzyl) propionaldehyde, hexyl cinnamic aldehyde, coumarin, linalool, formaldehyde, and fragrance components. After laundering, all fabrics were vertically air-dried at ambient room temperature.

Table 1: CIE L*, a* and b* color coordinates, whiteness index (WI_{CIE}) and color strength (K/S) of investigated control unwashed fabrics

Fabric code	Color	Chemical composition	L*	a*	b*	WI_{CIE}	K/S
W1	white	33% PES/67% Cotton	93.88	1.67	-9.85	132.7	
W2	white	40% PES/60% Cotton	95.17	1.30	-6.38	116.8	
W3	white	45% PES/55% Cotton	94.23	2.21	-8.52	124.5	
W4	white	45% PES/55% Cotton	92.00	1.70	-6.82	114.4	
W5	white	45% PES/55% Cotton	94.81	2.05	-9.76	131.3	
W6	white	50% PES/50% Cotton	94.62	2.21	-9.46	130.5	
W7	white	50% PES/50% Cotton	92.65	1.40	-10.32	128.4	
W8	white	50% PES/50% Cotton	94.43	1.20	-8.61	126.4	
W9	white	65% PES/35% Cotton	92.70	1.73	-10.11	128.7	
W10	white	65% PES/35% Cotton	92.92	1.56	-9.47	126.9	
L1	light gray	100 % Cotton	85.52	-0.83	0.10		2.2
L2	light blue	100 % Cotton	60.2	1.77	-13.17		4.9
L3	light blue	100 % Cotton	78.44	-0.57	-22.67		1.9
L4	light yellow	100 % Cotton	85.97	2.56	0.98		0.8
L5	light blue	50% PES/50% Cotton	79.36	0.82	-19.08		1.0
D1	dark red	100 % Cotton	34.58	41.27	14.99		19.1
D2	black	35% PES/65% Cotton	18.28	-0.04	-0.64		29.9
D3	black	45% PES/55% Cotton	17.32	0.13	-1.28		23.2
D4	black	50% PES/50% Cotton	17.36	0.37	-1.05		22.4
D5	black	65% PES/35% Cotton	19.98	1.04	-1.34		24.4

2.3 Testing methods

The quality assessment of both white and colored fabrics was conducted by measuring the whiteness index (WI_{CIE}), CIE L*, a*, b* color coordinates, color strength (K/S), and color difference (ΔE*). The whiteness index and CIE L*, a*, b* values were determined according to ISO 105-J02:1999 and ISO 105-J01:1997, respectively, using an X-Rite 7i spectrophotometer under D65 illumination and a 10° standard observer. For each fabric sample, ten measurements were recorded, and the mean value was used for analysis. The color difference (ΔE*) between control and laundered samples was calculated using the CIELab coordinates, based on the following equation:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

Where: $\Delta L^* = L^*_{sample} - L^*_{standard}$; $\Delta a^* = a^*_{sample} - a^*_{standard}$, and $\Delta b^* = b^*_{sample} - b^*_{standard}$.

Each fabric sample was categorized based on the magnitude of its ΔE* value into five levels of visual color difference: ΔE* < 0.2 was considered 'Not visible', 0.2 ≤ ΔE* < 1.0 as 'Very small', 1.0 ≤ ΔE* < 3.0 as 'Small', 3.0 ≤ ΔE* < 6.0 as 'Medium', and ΔE* > 6.0 as 'Large'. Additionally, ΔE* values were converted into grayscale ratings on a scale from 1 to 5 in accordance with ISO 105-A01:2010. The color strength (K/S), representing the depth or intensity of surface dye, was calculated using the Kubelka–Munk equation based on reflectance values measured at the wavelength of maximum absorption (λ_{max}):

$$K/S = \frac{(1 - R_{\lambda\max})^2}{2R_{\lambda\max}}$$

Where: K is the absorption coefficient, depending on the concentration of the colorant; S is scattering coefficient, caused by the dyed substrate and R is reflectance of the color sample at λ_{max} and is directly proportional to the concentration.

The higher the K/S value indicates the higher the color yield of the colored fabric [2-4].

3. RESULTS AND DISCUSSION

3.1. Laundering of white fabrics

The whiteness index of the control and laundered fabrics—after 25 wash cycles using powder detergent (PD) and liquid detergent (LD), as shown in Figure 1—was significantly influenced by both the laundering process and detergent type. Fabrics laundered with PD exhibited greater resistance to whiteness reduction compared to those laundered with LD. This is attributed to the presence of sodium perborate in PD, which acts as a source of hydrogen peroxide and provides effective bleaching action at temperatures above 40 °C [22]. In addition, PD formulations typically include a bleach activator [14] and optical brighteners, which enhance the perceived whiteness of fabrics by absorbing ultraviolet light and re-emitting it in the visible spectrum [23,24].

Optical brighteners are generally deposited on the fabric surface during laundering; however, they can be removed or degraded over time, similar to the fading of dyes, leading to a decline in whiteness [24]. In the case of PD, it is likely that these brighteners are continually redeposited during each wash cycle, helping to maintain or partially restore the whiteness index. In contrast, the absence of optical brighteners in LD formulations contributes to a more pronounced and irreversible reduction in whiteness index when compared to fabrics laundered with PD.

The observed reduction in the whiteness index is closely associated with measurable shifts in the CIE L*, a*, and b* color coordinates, as detailed in Tables 2 and 3. Irrespective of the detergent type, all laun-

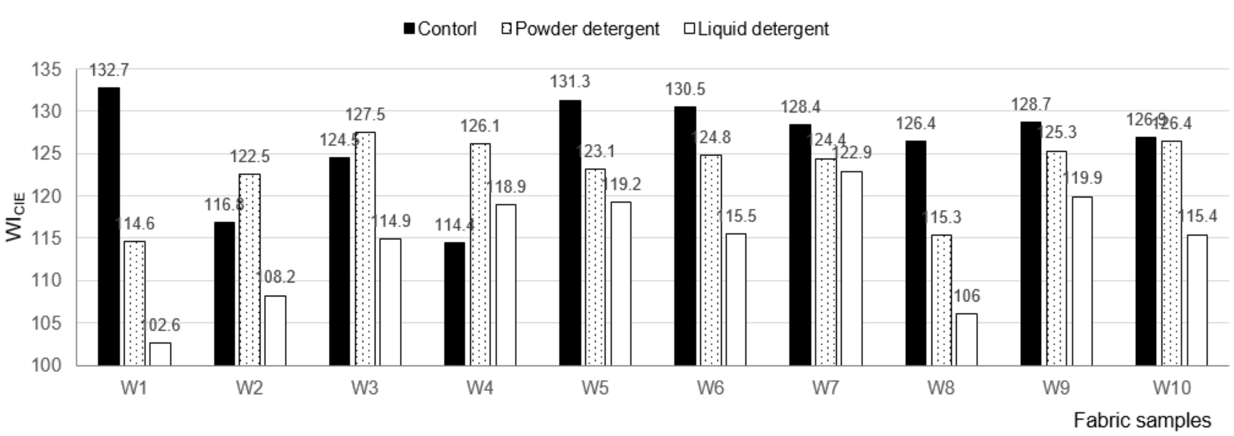

Figure 1: Whiteness index after 25 wash cycles: control vs. powder and liquid detergents.

dered fabrics demonstrated a general decrease in lightness, evident from the negative ΔL* values. In addition, changes in the Δa* and Δb* coordinates indicated perceptible alterations in red-green and yellow-blue color coordinates, reflecting dye degradation or surface changes affecting color perception. These colorimetric shifts were consistently more pronounced in fabrics laundered with PD compared to those washed with LD. The stronger impact of PD can be attributed to the presence of bleaching agents and optical brighteners, which, while effective in enhancing whiteness in white textiles, can accelerate color degradation and surface dulling in light or dark colored fabrics. Conversely, LD formulations, typically free from aggressive whitening additives, had a milder effect on color stability and fabric appearance. These results highlight the significant role of detergent composition in influencing the optical and visual properties of textiles subjected to repeated laundering.

3.2. Laundering of colored fabrics

The influence of repeated laundering with powder detergent (PD) and liquid detergent (LD) on fabric color strength is presented in Figures 2 and 3.

Table 2: CIE L*, a * and b* color coordinates of control white fabrics (C) and laundered with powder (PD) and liquid (LD) detergents

Fabric code	L*			a*			b*		
	C	PD	LD	C	PD	LD	C	PD	LD
W1	93.88	91.84	90.47	1.67	1.24	1.70	-9.85	-7.37	-5.37
W2	95.17	93.43	91.30	1.30	1.80	2.05	-6.38	-8.43	-6.24
W3	94.23	93.27	91.29	2.21	2.28	2.32	-8.52	-9.61	-7.67
W4	92.00	94.62	90.78	1.70	2.00	2.68	-6.82	-8.73	-8.76
W5	94.81	93.22	91.35	2.05	1.95	1.90	-9.76	-8.67	-5.59
W6	94.62	92.89	91.38	2.21	2.03	2.34	-9.46	-9.18	-7.77
W7	92.65	92.52	91.27	1.40	1.68	2.28	-10.32	-9.30	-10.07
W8	94.43	93.42	91.64	1.20	1.76	1.89	-8.61	-6.87	-5.61
W9	92.70	92.15	90.93	1.73	1.47	1.81	-10.11	-9.58	-8.91
W10	92.92	91.82	91.33	1.56	2.13	2.16	-9.47	-9.96	-7.77

Table 3: Differences in CIE L*, a* and b* coordinates between the white control (C) fabrics and fabrics laundered with powder (PD) and liquid (LD) detergents after 25 washing cycles

Fabric code	ΔL*		Δa*		Δb*	
	C-PD	C-LD	C-PD	C-LD	C-PD	C-LD
W1	-2.04	-3.41	-0.43	0.03	2.48	4.48
W2	-1.74	-3.87	0.50	0.75	-2.05	0.14
W3	-0.96	-2.94	0.07	0.11	-1.09	0.85
W4	2.62	-1.22	0.30	0.98	-1.91	-1.94
W5	-1.59	-3.46	-0.10	-0.15	1.09	4.17
W6	-1.73	-3.24	-0.18	0.13	0.28	1.69
W7	-0.13	-1.38	0.28	0.88	1.02	0.25
W8	-1.01	-2.79	0.56	0.69	1.74	3.00
W9	-0.55	-1.77	-0.26	0.08	0.53	1.20
W10	-1.10	-1.59	0.57	0.60	-0.49	1.70

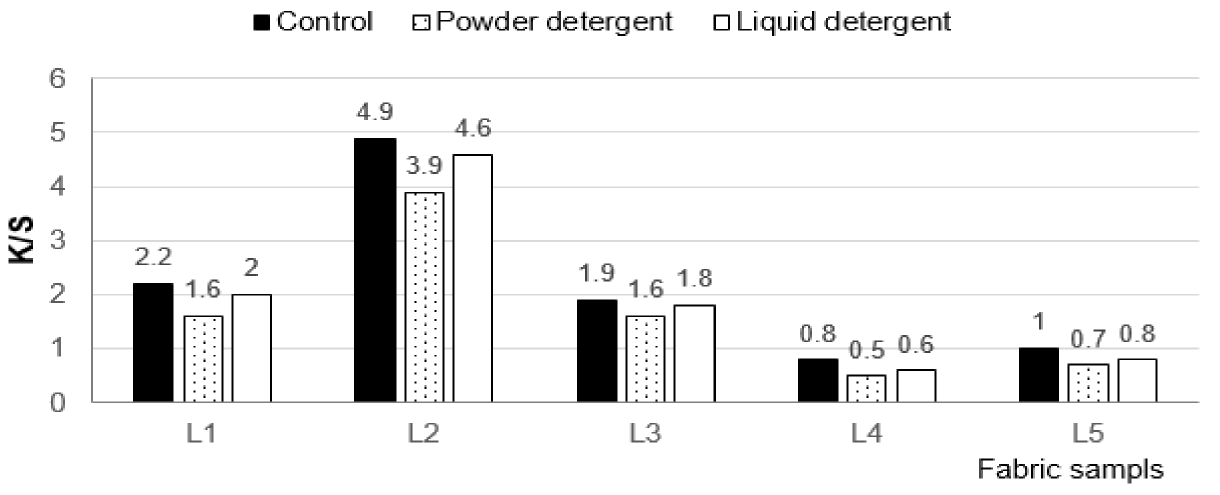

Figure 2: Color strength of light colored fabrics before and after 25 washing cycles with different detergent types

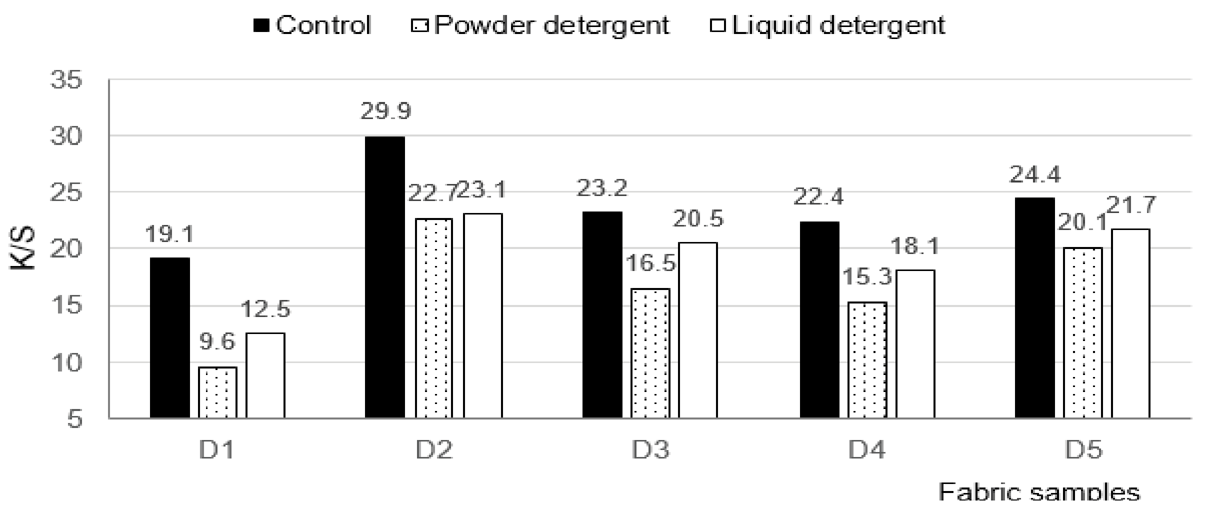

Figure 3: Color strength of dark colored fabrics before and after 25 washing cycles with different detergent types

Color strength, representing the visual intensity of dye, decreases progressively with the number of wash cycles, and is significantly influenced by the detergent type. Fabrics washed with LD generally exhibited higher retention of color strength compared to those treated with PD, which appeared lighter in shade. This decline in color strength for PD-laundered samples is likely attributed to the oxidative degradation and dye fading induced by bleaching agents and optical brighteners commonly present in powder formulations. While such additives are intended to enhance whiteness and brightness in white textiles, they can contribute to dye instability and color loss in colored fabrics [25]. In contrast, LD-typically formulated without bleaching systems-exerts a milder effect on dyes, leading to improved color preservation. These findings underscore the importance of detergent composition in maintaining the visual quality and longevity of colored textiles during routine laundering.

Further variations in the L*, a*, and b* color coordinates as a function of detergent type and repeated laundering cycles are presented in Tables 4 and 5. Fabrics laundered with powder detergent (PD) generally exhibited higher L* values, indicating a lighter or brighter appearance compared to those washed with liquid detergent (LD). Changes in the a* and b* coordinates, which represent shifts in red-green and yellow-blue tones respectively, were also observed. These colorimetric alterations were more pronounced in PD-treated fabrics, suggesting a greater impact of powder detergent on overall color shift compared to liquid formulations.

Table 4: CIE L*, a* and b* color coordinates of control light and dark (C) fabrics and fabrics laundered with powder (PD) and liquid (LD) detergents after 25 washing cycles

Fabric code	L*			a*			b*		
	C	PD	LD	C	PD	LD	C	PD	LD
L1	85.52	89.11	85.46	-0.83	2.36	2.08	0.10	-6.98	-5.72
L2	60.2	63.61	59.69	1.77	2.77	1.76	-13.17	-13.67	-12.92
L3	78.44	83.21	79.24	-0.57	-0.48	-0.58	-22.67	-19.45	-19.15
L4	85.97	86.72	85.65	2.56	2.11	2.29	0.98	-0.95	-0.24
L5	79.36	81.67	80.98	0.82	1.71	1.64	-19.08	-16.04	-15.89
D1	34.58	36.15	34.40	41.27	39.59	40.14	14.99	12.08	13.79
D2	18.28	20.84	18.42	-0.04	-0.46	-0.11	-0.64	-2.58	-1.31
D3	17.32	19.64	18.71	0.13	-0.84	-0.38	-1.28	-3.06	-2.41
D4	17.36	20.4	18.53	0.37	0.71	0.69	-1.05	-3.25	-1.59
D5	19.98	27.35	19.50	1.04	2.08	1.26	-1.34	-3.36	-1.37

Table 5: Differences in CIE L*, a* and b* color coordinates between the control light and dark (C) fabrics and fabrics laundered with powder (PD) and liquid (LD) detergents after 25 washing cycles

Fabric code	ΔL*		Δa*		Δb*	
	C-PD	C-LD	C-PD	C-LD	C-PD	C-LD
L1	3.59	-0.06	3.19	2.91	-7.08	-5.82
L2	3.41	-0.51	1	-0.01	-0.50	0.25
L3	4.77	0.8	0.09	-0.01	3.22	3.52
L4	0.75	-0.32	-0.45	-0.27	-1.93	-1.22
L5	2.31	1,62	0.89	0.82	3.04	3.19
D1	1.57	-0.18	-1.68	-1.13	-2.91	-1.20
D2	2.56	0.14	-0.42	-0.07	-1.94	-0.67
D3	2.32	1.39	-0.97	-0.51	-1.78	-1.13
D4	3.04	1.17	0.34	0.32	-2.20	-0.54
D5	7.37	-0.48	1.04	0.22	-2.02	-0.03

The overall color changes of the laundered fabrics were evaluated using ΔE values, derived from the L*, a*, and b* color coordinates, as shown in Table 6. Higher ΔE* values correspond to more pronounced color differences. Across all fabric codes (L1–L5, D1–D5), fabrics laundered with powder detergent (C-PD) exhibit consistently higher ΔE* values compared to those laundered with liquid detergent (C-LD). This trend is particularly pronounced in L1, L3, and D5, where ΔE* after PD laundering approaches or exceeds 6–8 units, signifying substantial visible color change. In contrast, the corresponding C-LD values are noticeably lower, especially for L2, L4, D2, and D5, where the ΔE* remains below 2, indicating superior color retention.

Most fabrics laundered with liquid detergent (LD) exhibited ΔE* values within the second (0.2–1.0) and third (1.0–3.0) categories, indicating very small to small color differences-typically imperceptible to the human eye-and corresponding to grayscale ratings of 4–5 and 4, reflecting very good to excellent colorfastness. In contrast, fabrics washed with powder detergent (PD) generally showed higher ΔE* values, falling into the fourth category (ΔE* 3.0–6.0), which indicates a medium color difference and a lower grayscale rating. The superior colorfastness of fabrics laundered with LD is attributed to the absence of bleaching agents and optical brighteners, which are known to accelerate dye degradation in colored fabrics.

Table 6: Color differences (ΔE*) between the control light and dark colored fabrics (C) and fabric laundered with powder (PD) and liquid (LD) detergents after 25 washing cycles

Fabric code	ΔE*		Visual color difference		Gray scale	
	C-PD	C-LD	C-PD	C-LD	C-PD	C-LD
L1	8.56	6.51	large	large	2-1	2
L2	3.59	0.57	medium	very small	3	4-5
L3	5.76	3.61	medium	medium	3-2	3
L4	2.12	1.29	small	small	4-3	4
L5	3.92	3.67	medium	medium	3	3
D1	3.71	1.66	medium	small	3	4
D2	3.24	0.69	medium	very small	3	4-5
D3	3.08	1.86	medium	small	3-2	4
D4	3.77	1.33	medium	small	3-2	4
D5	7.71	0.53	large	very small	2-1	4-5

4. CONCLUSION

This study establishes that repeated laundering exerts a measurable and detergent-dependent impact on the optical integrity of cotton-based textiles across both light and dark colored fabrics. Powder detergent formulations, characterized by oxidative bleaching agents and optical brighteners, induced elevated L* values and significantly higher ΔE* shifts in dark-colored fabrics, indicating substantial chromatic degradation and dye instability. Conversely, liquid detergents-engineered without harsh bleaching agents-exhibited enhanced chromatic fidelity and superior colorfastness in colored fabrics.

These results underscore a critical performance trade-off affecting long-term color retention, reinforcing the imperative for detergent formulations to be precisely tailored to fiber composition, fabric coloration, and intended application. Beyond performance metrics, the findings inform the strategic design of next-generation detergent formulations and laundering protocols that balance aesthetic preservation, fabric longevity, and environmental impact. This research supports the advancement of sustainable textile care technologies aligned with both consumer expectations and eco-efficient industrial practices.

REFERENCES

[1] Sanad A.R. (2016). Consumer attitude and purchase decision towards textiles and apparel products, *World Journal of Textile Engineering and Technology*, 2, 16-30.

[2] Toshikj E., Prangoski B. (2022). Grey level co-occurrence matrix (GLCM) for textile print analysis, *Tekstilna Industrija*, 70 (4), 34-40.

[3] Toshikj E., Prangoski B. (2022). Textile sublimation printing: impact of total ink limiting level and sublimation transfer paper on black print quality, *Tekstil ve Konfeksiyon*, 33 (4), 366-374.

[4] Toshikj E., Prangoski B. (2023). Textile sublimation printing: GLCM print mottle assessment of black printed fabric, *Materials Science-Medžiagotyra*, 29 (3), 366-374.

[5] Golomeova Longurova S., Jordeva S., Zhezhova S., Kuzmanoska V, Mojsov K., Andronikov D. (2022). The effect of fabric structure parameters on dimensional stability after domestic washing, *Tekstilna Industrija*, 70 (2), 22-27.

[6] Toshikj E., Demboski G., Jordanov I., Mangovska B. (2019). Functional properties and seam puckering on cotton shirt influenced by laundering, *Tekstilec*, 62 (1), 4-11.

[7] Toshikj E., Jordanov I., Demboski G., Mangovska B. (2016). Influence of multiple laundering on cotton shirts properties, *Tekstil ve Konfeksíyon*, 26 (4), 393-399.

[8] Toshikj E., Demboski G., Jordanov I., Mangovska B. (2015) Influence on seam type and laundering on seam puckering and functional properties of cotton/polyester shirt fabrics, AATCC Review, 15 (2), 41-49.

[9] Toshikj E., Mangovska B. (2011). Effect of maundering of cotton knitted fabrics with different detergents on the dimension stability and colour fastness, *Tekstilna Industrija*, 59 (2), 5-11.

[10] Hauthal H.G. (2012). Washing at low temperature-saving energy, ensuring hygiene, *Tenside Surfactants Detergents*, 49 (2), 171-177.

[11] Scheid F., Lambert E., Maitra W., Niestrath M., Fah D., Pormann C., Gorny S.,Stamminger R. (2016). Textile quality depletion due to housholder machine wash-ways to measure and impacts of wash duration and temperature on textiles, *Tenside Surfactants Detergents*, 53 (5), 438-444.

[12] Honisch M., Stamminger R., Bockmuhl P.D. (2014). Impact of wash cycle time, temperature and detergent formulation on the hygiene effectiveness of domestic laundering, *Journal of Applied Microbiology*, 117 (6), 1787-1797.

[13] Bajpai D., Tyagai K.V. (2007). Laundry detergents: an overview, *Journal of Oleo Science*, 56 (7), 327-340.

[14] Ferri A., Osset M., Abeliotis K., Amber K., Candon C., Owens J., Stamminger S. (2016) Laundry performance: effect of detergent and additives on consumer satisfaction, *Tenside Surfactant Detergents*, 53 (4), 375-386.

[15] Laitala K., Kjeldsberg M. (2012). Cleaning effect of alternative laundry products. A comparison of soap nuts, laundry balls, washing pellets, laundry magnets, water and regular detergent, *Household and Personal Care Today*, 7 (4), 53-56.

[16] Rachna K., Tyagai K. V (2006). Gels: novels detergents of laundry application, *Journal of Oleo Science*, 55 (11), 555-562.

[17] Vojcic L., Pitzler C., Korfer G., Jakob F., Martines R., Maurer H.K., Schwaneberg U. (2015). Advances in proteases engineering for laundry detergents, *New Biotechnology*, 32 (6), 629-634.

[18] Pušić T, Jeličić J., Nuber M. (2007) Investigation of bleach active compounds in washing bath, *Tesktil* 56 (7), 407-411.

[19] Sabatini A.D. (2012). Mechanistic studies of particulate soil detergency: I. hydrophobic soil removal, *Journal of Surfactants and Detergents*, 15 (3), 277-289.

[20] Cireli A., Sarisik M., Kutlu B., Yaman V. (2004). The Effect of washing conditions on soil removal in domestic laundering processes, *AUTEX Research Journal*, 4 (2), 101-112.

[21] Samanta K.A., Mitra S. (2004). Efficacy of selective surfactant/detergents as washing agents on soiled white and dyed cotton fabrics, *Indian Journal of Fibre and Textile Research*, 29 (2), 223-232.

[22] Hazenkamp F.M., Bachmann F., Dannacher J.J., Schlingloff G (2001) Kinetic aspects of dye-transfer inhibition by catalytic oxidation, *Journal of Surfactant and Detergents*, 4 (1), 65-73.

[23] Iqbal A., Chowdhury N., Jubayer M.U., Molla B.J., Hossain M. (2014). Effect of optical brightening agent on different types of fabrics, *Daffodil International University Journal of Science and Technology*, 9 (2), 37-41.

[24] Mendelson C. (2010). Laundry: The home comforts book of caring clothes and linens, Scribner, New York, USA, pp-83-84.

[25] Wang Y., Zhao T., Bi X., Lv C. (2024). Synthesis of novel carbine dyes and investigation of their dyeing properties and reaction mechanism for various fabrics, Dye and Pigments, 221, 111784.

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