DETERGENT-INDUCED COLOR CHANGES IN COTTON-BASED FABRICS SUBJECTED TO REPEATED LAUNDERING

Review scientific paper
DOI: 10.5937/CT_ITI25011T

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ABSTRACT: *Color retention is a fundamental quality metric for textiles, directly influencing consumer satisfaction and environmental sustainability. This study systematically evaluates the effects of 25 laundering cycles on the chromatic stability of light and dark dyed cotton and cotton/polyester blends, utilizing commercially available powder and liquid detergents. Quantitative assessments, including CIELab color coordinates, spectral reflectance-derived color strength (K/S), and color difference (ΔE*), reveal stark contrasts in performance. Powder detergents induce significant dye degradation and color fading, whereas liquid formulations—lacking aggressive bleaching agents—maintain markedly higher color fidelity with substantially lower ΔE* metrics. These findings expose a vital trade-off between chemical aggressiveness and aesthetic preservation, emphasizing the need for environmentally sustainable detergent innovations that optimize fabric care, color longevity, and eco-efficiency. The results inform the development of next-generation textile maintenance protocols balancing performance with sustainability, ultimately supporting eco-conscious consumer choices and industrial practices.*

Keywords: *Color retention, textile laundering, detergent formulation, CIELab color coordinates, color fastness, sustainable fabric care.*

PROMENE BOJE NA TKANINAMA NA BAZI PAMUKA IZAZVANE DETERŽENTOM TOKOM PONAVLJENOG PRANJA

APSTRAKT: *Postojanost boje je fundamentalna metrika kvaliteta za tekstil, direktno utičući na zadovoljstvo potrošača i ekološku održivost. Ova studija sistematski procenjuje efekte 25 ciklusa pranja na hromatsku stabilnost svetlo i tamno obojenih tkanina od pamuka i mešavine pamuka/poliestera, koristeći komercijalno dostupne praškaste i tečne deterdžente. Kvantitativna merenja, uključujući CIELab koordinate boje, jačinu boje izvedenu iz spektralne refleksije (K/S), i razliku u boji (ΔE), otkrivaju oštre kontraste u performansama. Praškasti deterdženti izazivaju značajnu degradaciju boje i gubitak boje, dok tečne formulacije — bez agresivnih agenasa za izbeljivanje — održavaju primetno veću*

vernost boje sa znatno nižim ΔE vrednostima. Ovi nalazi otkrivaju ključni kompromis između hemijske agresivnosti i očuvanja estetike, naglašavajući potrebu za ekološki održivim inovacijama deterdženata koje optimizuju negu tkanina, dugotrajnost boje i eko-efikasnost. Rezultati informišu razvoj protokola za održavanje tekstila sledeće generacije koji balansiraju performanse sa održivošću, na kraju podržavajući ekološki svesne izbore potrošača i industrijske prakse.

Ključne reči: *Postojanost boje, pranje tekstila, formulacija deterženta, CIELab koordinate boje, postojanost boje.*

1. INTRODUCTION

In contemporary textile consumption, garment quality is no longer judged solely by aesthetics or comfort but increasingly by parameters such as durability, ease of care, and environmental impact. Among these, color retention has emerged as a primary determinant of consumer satisfaction, often outranking tactile properties, fabric composition, and price in purchase decisions [1]. The preservation of a fabric's original color appearance throughout its service life is widely recognized as a core indicator of product value and consumer trust. However, color degradation during laundering remains a pervasive challenge within the textile industry, frequently resulting in premature garment disposal, elevated replacement rates, and a greater environmental burden. Garments dyed in solid shades or finished via pigment, reactive, or sublimation printing methods are particularly susceptible to chromatic instability under repeated laundering conditions [2–4]. Ensuring color durability is therefore essential not only for maintaining aesthetic appeal but also for enhancing product longevity and reducing textile waste.

Laundering, the most frequent and chemically aggressive form of garment maintenance, subjects' fabrics to a combination of mechanical, thermal, and chemical stresses that accelerate wear and diminish visual quality. Common consequences include dye fading, bleeding, and loss of whiteness—all of which reduce garment appeal over time [5–9]. These degradative processes not only alter visual perception but have broader implications for textile sustainability, particularly when viewed through the lens of extended product life cycles and circular material flows. According to the Sinner Circle model, laundering effectiveness is governed by the interaction of four critical variables: temperature, time, mechanical agitation, and chemical action [10]. Optimizing one factor often necessitates adjusting others to maintain cleaning efficacy without compromising fabric integrity [11].

Among these, detergent formulation plays a pivotal role in determining both cleaning outcomes and fiber preservation [12]. Commercial detergents are complex chemical systems incorporating surfactants, enzymes, builders, bleaching agents, optical brighteners, and stabilizers [13]. Powder and liquid detergents dominate the global market [14], yet differ significantly in their chemical profiles and interaction with textiles [13,15–17]. Powders commonly contain activated oxygen bleaches and brighteners, which enhance fabric whiteness but may induce oxidative dye degradation, especially in dark-colored

garments [18,19]. In contrast, liquids are typically bleach-free and rely on milder surfactant systems that reduce dye damage while providing adequate cleaning—particularly under lower temperature conditions.

Understanding these formulation-driven effects is critical for advancing sustainable laundering practices, prolonging textile lifespan, and reducing environmental impact [14]. Despite increased commercial availability and eco-labeling, limited research has comparatively evaluated the long-term impact of detergent type on both light and dark color across real-world laundering cycles and fiber blends. This study addresses that gap by assessing optical property changes—CIELab color coordinates and color strength (K/S)—in cotton and cotton/polyester fabrics subjected to 25 domestic wash cycles using commercial powder and liquid detergents. The findings provide robust, data-driven guidance for formulation scientists, textile engineers, and sustainability-focused practitioners.

2. EXPERIMENTAL PART

2.1. Materials

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

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

Fabric code	Color	Chemical composition	L*	a*	b*	K/S
FL1	light gray	100 % Cotton	85.52	-0.83	0.10	2.2
FL2	light blue	100 % Cotton	60.2	1.77	-13.17	4.9
FL3	light blue	100 % Cotton	78.44	-0.57	-22.67	1.9
FL4	light yellow	100 % Cotton	85.97	2.56	0.98	0.8
FL5	light blue	50% PES/50% Cotton	79.36	0.82	-19.08	1.0
FD1	dark red	100 % Cotton	34.58	41.27	14.99	19.1
FD2	black	35% PES/65% Cotton	18.28	-0.04	-0.64	29.9
FD3	black	45% PES/55% Cotton	17.32	0.13	-1.28	23.2
FD4	black	50% PES/50% Cotton	17.36	0.37	-1.05	22.4
FD5	black	65% PES/35% Cotton	19.98	1.04	-1.34	24.4

2.2. Laundering procedure

Light and dark colored textile fabrics were subjected to rigorous 25-cycle laundering protocols adhering to ISO 6330:2010 standards. Thermal profiles were precisely controlled: 60°C for light fabrics and 40°C for dark. Samples were processed individually using either a complex powder detergent (PD)—featuring surfactants, enzymes, bleaching agents, and optical brighteners—or a distinct liquid detergent (LD)—primarily anionic surfactants with specific fragrance chemistries. Post-wash, all samples underwent vertical air-drying at standardized ambient room temperature to ensure controlled moisture removal kinetics.

2.3. Testing methods

The quality of colored fabrics was evaluated by measuring CIE L*, a*, b* color coordinates, color difference (ΔE*), and color strength (K/S). L*, a*, b* values were obtained using an X-Rite 7i spectrophotometer under D65 illumination with a 10° standard observer, in accordance with ISO 105-J01:1997. Ten readings per sample were averaged. ΔE* was calculated from the CIELab coordinates.

Each fabric sample was categorized based on the magnitude of its ΔE* value into five levels of visual color difference: $\Delta E^* < 0.2$ was considered 'Not visible', $0.2 \leq \Delta E^* < 1.0$ as 'Very small', $1.0 \leq \Delta E^* < 3.0$ as 'Small', $3.0 \leq \Delta E^* < 6.0$ as 'Medium', and $\Delta E^* > 6.0$ 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}).The higher the K/S value indicates the higher the color yield of the dyed fabric [2-4].

3. RESULTS AND DISCUSSION

The influence of repeated laundering with powder detergent (PD) and liquid detergent (LD) on fabric color strength is depicted in Figures 2 and 3. Color strength (K/S), a quantitative measure reflecting the intensity and saturation of a fabric’s dye, demonstrated a progressive decline with an increasing number of wash cycles. However, the extent and rate of this decline were significantly dependent on the detergent formulation used. Fabrics subjected to laundering with LD consistently retained a higher proportion of their original color strength across all cycles when compared to those washed with PD, indicating a superior resistance to dye fading.

This difference is primarily attributed to the chemical composition of each detergent type. PD formulations typically contain bleaching agents and optical brighteners intended to maximize the whiteness and luminosity of pale textiles. While effective for light-colored fabrics, these oxidative additives can accelerate dye degradation, weaken dye-fiber bonds, and lead to marked instability in colored textiles, ultimately causing significant loss of color intensity [20]. Conversely, LD formulations are generally devoid of aggressive oxidizers and thus deliver a milder washing action that better preserves the structural integrity of dye molecules and maintains the original color and visual quality of the textiles. These findings

highlight the critical role of detergent chemistry in ensuring optimal colorfastness and in prolonging the aesthetic lifespan of colored fabrics through repeated laundering.

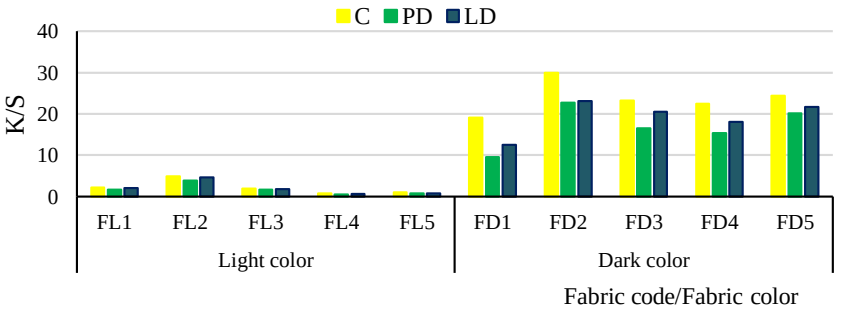

Figure 1: Color strength of light and dark colored fabris before and after 25 washing cycles with powder and liquid detergent

Additional variations in the L*, a*, and b* color coordinates as influenced by detergent type and repeated laundering cycles are presented in Table 2. Fabrics laundered with PD generally exhibited higher L* values, indicating a lighter or brighter visual appearance compared to those washed with LD. Notable changes were also observed in the a* and b* coordinates, which correspond to shifts along the red–green and yellow–blue axes, respectively. These colorimetric shifts were more pronounced in fabrics treated with PD, suggesting that powder detergent has a stronger effect on overall color balance than its liquid counterpart.

Table 2: CIEL*, a* and b* color coordinates, and color strength (K/S) of investigated control and washed fabrics

Fabric code	L*			a*			b*		
	C	PD	LD	C	PD	LD	C	PD	LD
FL1	85.52	89.11	85.46	-0.83	2.36	2.08	0.10	-6.98	-5.72
FL2	60.2	63.61	59.69	1.77	2.77	1.76	-13.17	-13.67	-12.92
FL3	78.44	83.21	79.24	-0.57	-0.48	-0.58	-22.67	-19.45	-19.15
FL4	85.97	86.72	85.65	2.56	2.11	2.29	0.98	-0.95	-0.24
FL5	79.36	81.67	80.98	0.82	1.71	1.64	-19.08	-16.04	-15.89
FD1	34.58	36.15	34.40	41.27	39.59	40.14	14.99	12.08	13.79
FD2	18.28	20.84	18.42	-0.04	-0.46	-0.11	-0.64	-2.58	-1.31
FD3	17.32	19.64	18.71	0.13	-0.84	-0.38	-1.28	-3.06	-2.41
FD4	17.36	20.4	18.53	0.37	0.71	0.69	-1.05	-3.25	-1.59
FD5	19.98	27.35	19.50	1.04	2.08	1.26	-1.34	-3.36	-1.37

Figure 2 compares the color difference (ΔE*) of various fabric codes after laundering, illustrating the effects of PD and LD, with the original (control) fabrics (C). Higher ΔE* values indicate greater color change from the control sample.
Across all fabric codes (FL1–FL5, FD1–FD5), 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 FL1, FL3, and FD5, 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 FL2, FL4, FD2, and FD5, where the ΔE* remains below 2, indicating superior color retention.
This pattern demonstrates that powder detergent causes greater color alteration, likely due to the presence of bleaching agents and optical brighteners known to accelerate dye degradation. Liquid detergent, in contrast, leads to smaller ΔE* values, thus better preserving the original color of the fabrics.

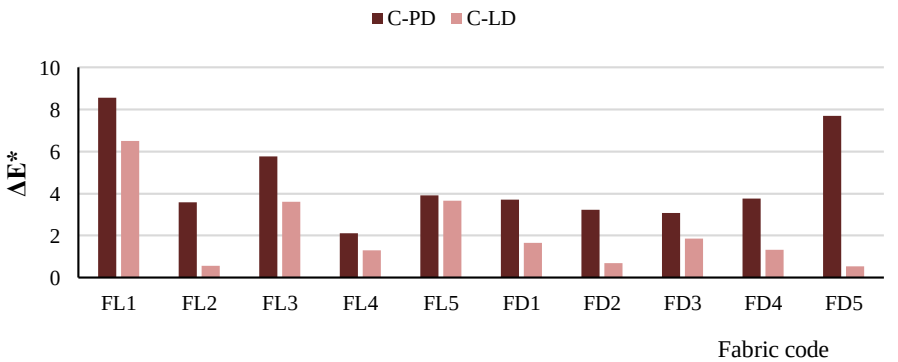

Figure 2: Color difference between the control light and dark colored fabrics (C) and fabric lundered with powder (PD) and liquid (LD) detergents after 25 washing cycles

Fabrics washed with LD mostly showed ΔE* values below 3.0, corresponding to minimal, often imperceptible color changes and high grayscale ratings (4–5). In contrast, PD led to higher ΔE* values (3.0–6.0), signifying more noticeable color changes and reduced colorfastness.

3. CONCLUSION

This study demonstrates that repeated laundering significantly influences the optical properties of both light and dark colored cotton-based fabrics, with outcomes strongly dependent on the type of detergent used. Fabrics washed with powder detergent—containing bleaching agents and optical brighteners—exhibited higher whiteness retention and smaller shifts in L*, a*, and b* color coordinates for textiles. However, the same detergent formulation led to greater lightness and more pronounced color changes (higher ΔE* values) in dark colored fabrics, indicating substantial dye degradation. In contrast,

fabrics laundered with liquid detergent, which lacks aggressive bleaching systems and brighteners, showed superior colorfastness in colored fabrics. These findings underscore the trade-off between enhanced color retention, highlighting the need for tailored detergent selection based on fabric type and desired performance. Moreover, the results contribute valuable insights for the development of detergent formulations and laundering protocols that support both fabric care and sustainable textile maintenance.

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