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Color Fastness of Untreated Textiles in Direct-to-Garment Printing

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APPLIED RESEARCH

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Color Fastness of Untreated Textiles in Direct-to-Garment Printing

ABSTRACT

Direct-to-garment (DTG) printing is a relatively new technology that prints directly onto a textile. There are several DTG printing units of varying capabilities, costs, and requirements on the market today. Many units require textiles to be pretreated prior to printing; however, the Roland VersaSTUDIO BT-12 printer does not due to its inability to print white ink. This DTG printer is currently being used in an introductory design and print production course in which students purchase t-shirts of various fabrics and print designs on them. The purpose of this study is to test various types of untreated fabrics to determine which have the best overall color fastness and quality after laundering. The results of this research will be used to make recommendations to students regarding which t-shirt fabrics to purchase for DTG printing on the Roland unit, as well as to provide consumers and manufacturers with updated information as it relates to untreated textile options for DTG printers that do not print white ink.

Introduction

Direct-to-garment (DTG) printing is a newer print technology that utilizes a digital printhead to print directly onto a textile (Farag, n.d.). Many DTG printing units require pretreatment of fabric before image transfer. However, some cyan, magenta, yellow, and black (CMYK) printers, specifically those recommended for use on white or light-colored garments, require no pretreatment (Hunter, 2021). The Roland VersaSTUDIO BT-12 printer used in the researcher's GC 1050 Applications of Digital Graphics course is one such unit. This experimental research project seeks to examine a variety of fabrics and fabric blends to determine the best color fastness, which refers to color that does not run or fade after laundering.

The significance of this project is two-fold. With regards to education and the body of knowledge, the results of this study will allow the researcher to make fabric recommendations to students when students are purchasing t-shirts for printing on the DTG printer. In addition, these findings will be incorporated into the researcher's teaching of the DTG printing unit. Since DTG printing is a newer technology, research related to color quality is somewhat limited. The results of this study can provide manufacturers and consumers with updated recommendations regarding colorfastness of untreated common textiles.

History

DTG printing originated in the United States in 1996 with the introduction of the "Revolution" printer developed by Matthew Rhome (2022). Later in 2005 Brother and Rhome created the first Brother DTG printer (Sepaniak, 2016). DTG printing continued to develop; however, the sales market remained rather stagnant until 2004, when Mimaki and Kornit introduced their DTG printing units (Robert, 2021). When DTG first came to market, the units could only print cyan, magenta, yellow, and black. This resulted in the inability to print on darker fabrics such as black, dark blue, and dark green due to lower color contrast with the ink color and fabric color (Robert, 2022). In 2005, white ink was introduced, allowing for the use of dark fabrics in DTG by printing the white ink layer first and adding the subsequent ink layers on top. However, due to the chemical makeup of the white ink, printers were encountering issues with the ink settling to the bottom of the container, clogging printheads. As a result, pretreatment of garments became necessary in order to create the proper chemical reaction (Robert, 2022).

DIRECT-TO-GARMENT PRINTING OVERVIEW

Direct-to-garment printing, or DTG, works much the same way as a home desktop printer; however, rather than using a paper substrate, textiles are used (Robert, 2021). As previously stated, DTG printing is a process that sprays ink directly onto to the textile using a modified inkjet technology. The process begins by pretreating the garment, which allows for the ink to adhere to the textile. Several pretreatment options and methods exist on the market today: 1) hand spraying

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the pretreatment directly onto the garment, 2) utilizing a pretreatment machine that automatically applies the pretreatment, or 3) purchasing garments that are pretreated by a manufacturer. After the pretreatment has dried, either by air drying or by heat press, the printing process can begin. All textiles, with the exception of white, require a white ink base layer be printed first followed by a second layer of the remaining colors, cyan, magenta, yellow, and black. Once printing is complete, the textile needs to be cured in order for the ink to better resist color fade after laundering.

The advantages of this newer technology include greater image detail and the ability to print a full range of colors. The process is also considered to be a more environmentally friendly process due to higher energy efficiency. As with other print processes, DTG also has disadvantages, which include limitations on the types of fabric that can be used, limited surface for application, and that the process is not ideal for large orders due to slower printing time.

TEXTILES IN DIRECT-TO-GARMENT PRINTING

DTG printing is a versatile process with regards to the variety of textiles available for printing. Generally speaking, the most suitable fabrics for DTG printing are cotton, combed cotton, organic cotton, linen, light-colored polyester and blends (Polyprint, n.d.). Cotton easily absorbs water-based inks; however, the consistency of the cotton can affect the overall print and durability. The thicker the material, the more the ink will be absorbed, thus resulting in more vibrant long-lasting color (Polyprint, n.d.). Linen is another option for DTG textile printing; however, it is not preferred due to its ability to wrinkle easily and its rough texture (Polyprint, n.d.). Polyester is a fabric commonly used in dye sublimation and has properties that cause it to repel water-based inks, which is why this is not a common fabric in DTG printing. The fabric properties require the garment to be pretreated prior to production, and it has been found that lighter-colored polyesters are more appropriate because of the higher color contrast with the inks (Polyprint, n.d.). Cotton, polyester, and other fabric blends were tested in this research.

PREVIOUS RESEARCH

Research on color fastness of textiles in DTG printing is rather limited. Some studies have been conducted related to the general color fastness of specific inks and fabrics, using varied print production processes. The Roland VersaSTUDIO BT-12 unit uses textile garment pigment (TGP) ink specifically formulated for textile printing (Hunter, 2021). Uddin et al. (2020) found that pigment printed textiles had very good color fastness along with high resistance to staining. Uddin et al.'s (2020) study analyzed the color fastness of various printing styles, such as pigment printing, rubber printing, and glitter printing, among others. Marie et al. (2013) concluded that the addition of a dispersing agent, ethylene glycol, defoamer, and diammonium phosphate to pigment inks can improve the stability and color fastness levels of inks dependent on substrate and ink color.

Many DTG printing units, including the Roland unit tested in this research, recommend high-quality, cotton fabrics for best color quality; however, some research has indicated that 100% cotton fabrics can lead to ink smearing and low color strength (Kim et al., 2022). Hassabo et al. (2023) found that the limitations of inkjet digital printing on cotton textiles were caused by a reactive coloring procedure. To solve this problem, the researchers suggested the addition of thickeners and other agents to the pretreatment of the fabric prior to printing. This study will add to the limited body of research on DTG printing and color fastness.

Methods and Procedures

The purpose of this project was to determine which uncoated textiles provided the best color fastness after laundering. The samples were produced using the Roland VersaSTUDIO BT-12 DTG printer. The first step in the procedure was to determine which textiles would be used to test. Eight samples were selected consisting of various fabric and fabric blends. Table 1 provides a breakdown of the types of samples.

n = 8

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Table 1.
Fabric Samples Tested

Sample # and Fabric Reference Code	Fabric
Sample 1 100P	100% polyester
Sample 2 70V30C	70% viscose from bamboo/30% cotton
Sample 3 65C35P	65% cotton/35% polyester
Sample 4 60P30C10R	60% polyester/30% cotton/10% rayon
Sample 5 60C40P	60% cotton/40% polyester
Sample 6 50P25C25R	50% polyester/25% cotton/25% rayon
Sample 7 100C	100% cotton
Sample 8 50C50P	50% cotton/50% polyester

The selected fabrics comprised cotton, polyester, and cotton and polyester blends. Polyester is a manufactured fiber consisting of the following properties: strong, crisp, resistant to stretching and shrinkage, quick drying, wrinkle resistant, abrasion resistant, resistant to many chemicals, low absorbency, static and pilling issues (FabricLink, 2023a). Fabric properties of cotton include varying thread counts, up to 2,000. It is a breathable fabric with high moisture-wicking capabilities. Cotton is also prone to pilling and bubbling and has medium heat retention and stretchability (Sewport, 2023). Fabric properties of bamboo include soft, smooth, good breathability, cool, anti-static, durable, and abrasion resistant (FabricLink, 2023b). Properties of rayon fabric are soft, highly absorbent, dyes and prints well, no static or pilling, and shrinkage (FabricLink, 2023c).

These fabrics required no pretreatment since the DTG printer used does not require pretreatment for production. A test target was then created to print on each sample. The target size and color were based off of a previous research study (Kim et al., 2022) which also analyzed color fastness after washing. The test target for this study was 6.9 inches by 7.9 inches total and comprised 100% cyan, 100% magenta, 100% yellow, and 100% black. A single layer of ink was applied per sample. This particular printing unit uses a specially formulated TGP ink. Pigment inks are more water and fade resistant in comparison to other inks. They are also known to be longer lasting and have better color stability (Altenew, n.d.). In order to prepare the material for printing on the Roland VersaSTUDIO BT-12, the sample was affixed to the 8.5-inch by 11-inch platen and ironed using the DTG heating unit for 30 seconds at 172°C (341°F). The sample was then loaded into the printing unit and the test target was printed, which took approximately 15 seconds. Lastly, each fabric was loaded back into the heating unit to be UV cured for 3 minutes at 172°C (341°F).

An initial prewash color measurement was first acquired using the i1Basic Pro 3 Plus spectrophotometer, which gathered CIELAB (International Commission on Illumination) color data. Each measurement was taken at approximately the same time of day in similar lighting conditions. The spectrophotometer was calibrated prior to each set of measurements. According to Phillips (2024), "The letters L*, a*, and b* represent each of the three values the CIELAB color space uses to measure objective color and calculate color differences" (p. 1). L* represents lightness from black to white, while a* and b* represent chromaticity (Phillips, 2024). The eight fabric samples were then laundered on a standard home washing and drying unit. The International Organization for Standardization (ISO) and the American Association of Textile Chemists and Colorists (AATCC) standards are available for testing color fastness; however, due to limited funding for supplies, it was determined that standard

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laundering units were more feasible options. In addition, the researcher wanted to simulate how students would be laundering t-shirts since one primary goal of the research was to make fabric recommendations for student projects. An informal survey was taken in class with the students to determine whether the majority of them wash clothing in hot or cold water and what drying setting is used. Based on the information gathered, the fabric samples were washed on the "normal" hot water setting, which is 49°C (120°F). This is consistent with the overall recommended AATCC 2A standard for machine washing. Original Tide liquid detergent was used in each round of washing. The samples were then dried on the "regular" dryer setting. No fabric softener or dryer sheets were added. Upon completion of the first laundering, color targets were measured using the spectrophotometer. The laundering and color measuring process was repeated an additional four times. Upon completing the color measurements, the data were input into Microsoft Excel, where a Delta E measurement was calculated.

Results

Delta E, in its simplest terms, is a number that represents the difference between two colors and is measured on a scale from 0 to 100 (Sands, 2016). According to Schuessler (n.d.), usual color perception ranges are represented by the following: ≤1.0: not perceptible to the human eye; 1–2: distinguishable through close attention; 2–10: perceptible at first sight; 11–49: colors are comparable to the opposite; and 100: colors are the opposite. For this particular research, a Delta E measurement was appropriate because the purpose of the study was to determine which fabric maintained the best color fastness after five launderings. The Delta E measurement provided the difference in color by comparing the initial prewash L*a*b* color readings to the post-laundering L*a*b* readings. Once color readings were acquired, the following Delta E formula was used to calculate the measurement for each process color on each fabric after each laundering: $= ((C5 - D5)^2 + (C6 - D6)^2 + (C7 - D7)^2)^{(1/2)}$.

Figure 1 data demonstrate that sample 1 (100P) performed the best with regards to color fastness, while sample 2 (70V30C) had the poorest Delta E readings. In relation to the Delta E scale, the sample 1 (100P) color difference is distinguishable by close inspection, while sample 2 (70V30C) colors are comparable to the opposite. In general, samples 3 (65C35P) and 5 (60C40P) performed relatively well, and samples

Figure 1.
CMYK Color Comparisons.

Note: Delta E CMYK color comparisons for laundering 1. Sample codes are as follows: 100P (100% polyester), 70V30C (70% viscose from bamboo 30% cotton), 65C35P (65% cotton/35% polyester), 60P30C10R (60% polyester/30% cotton/10% rayon), 60C40P (60% cotton/40% polyester), 50P25C25R (50% polyester/25% cotton/25% rayon), 100C (100% cotton), and 50C50P (50% cotton/50% polyester).

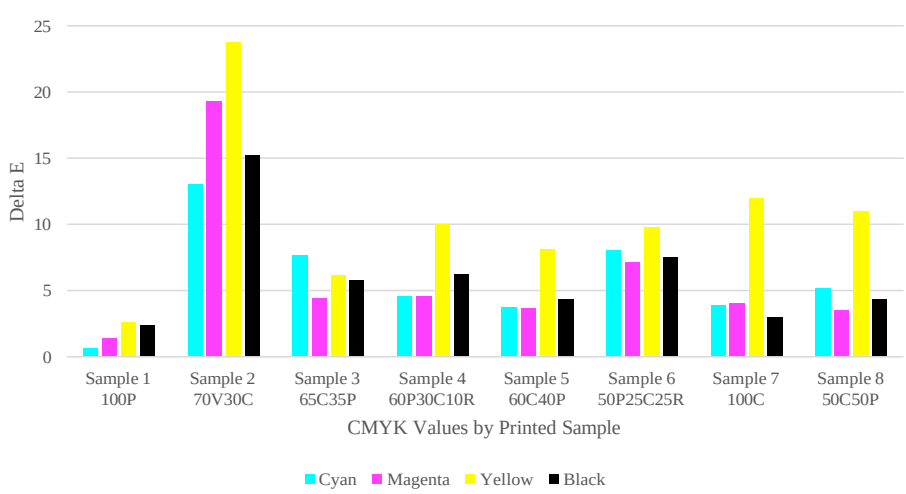

Table 2.
Precise Delta E Readings for Process Color and Printed Sample for Laundering 1.

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
Cyan	0.65	13.03	7.63	4.56	3.76	8.06	3.9	5.19
Magenta	1.39	19.33	4.41	4.56	3.65	7.16	4.02	3.5
Yellow	2.6	23.78	6.17	10	8.11	9.76	11.95	11.02
Black	2.38	15.22	5.79	6.21	4.39	7.51	2.97	4.39

4 (60P30C10R), 6 (50P25C25R), 7 (100C), and 8 (50C50P) had acceptable readings. All were perceptible at first sight with the exception of yellow. Figure 1 shows that all fabric samples had similar Delta E values, except for sample 1 which had low scores and sample 2 which had high scores in comparison to the other fabrics. Table 2 provides a breakdown of exact Delta E measurements for each sample and process color for laundering 1.

Figures 5, 6, and 7 showing a comparison of Delta E readings from launderings 2, 3, and 4 are located in Appendix A as well as Tables 4, 5, and 6 showing exact Delta E readings. In the second round of laundering, sample 1 had the best color fastness, and sample 2 had the worst. Samples 4, 5, 7, and 8 performed relatively well and consistent with each other, with Delta E's readings around 6 to 7, with the exception of high yellow values around 12 and 15. Samples 3 and 6 also had poor color fastness in comparison to the other fabrics. For reference, sample 1 had Delta E scores ranging from 0.4 to 3, while sample 2 had values from 15 to 29. At this point in laundering 3, all samples were performing relatively poorly with the exception of sample 1. Sample 1 had the best color fastness, ranging from approximately 2 to 4, and sample 2 had the worst, ranging from 18 to 29. Overall, sample 5 had the best performance behind sample 1. In laundering 4, again sample 1 had the best Delta E values, ranging from 1 to 5. Sample 2 had the poorest values, ranging from 18 to 33. Sample 5 performed the best after sample 1, with values around 7 and 8, with the exception of yellow coming in around 16. Samples 6 and 7 performed poorly behind sample 2 with ranges from 13 to 16 and 8 to 20.

Round 5 of laundering, below in Figure 2, shows that sample 1 maintained the best color fastness while sample 2 had the worst. The other samples were relatively consistent with each other in this round. All samples, with the exception of samples 1 and 3, had much higher yellow values than cyan, magenta, and black. Table 3 provides a breakdown of exact Delta E measurements for each sample and process color for laundering 5.

Samples were also photographed and visually inspected for best overall color quality. Figures 3 and 4 demonstrate the amount of color degradation that occurred after five launderings. Sample 1 performed well with a color fastness range of 2 to 4, while sample 2 performed quite poorly with a final color fastness range of 18 to 32. Upon inspection of sample 1, one does not notice a considerable amount of color quality loss; however, sample 2, shown in Figure 4, shows an impressive amount of color loss.

Discussion

Upon completion of five launderings, sample 1 proved to outperform all other fabrics tested with regards to color fastness and best color quality based on visual inspection. Sample 2 consistently performed the worst in all rounds of testing. The remaining samples, which all contained a percentage of cotton, appeared to perform similarly based on Delta E values. Samples 4 and 6, which contained a small percentage of rayon in addition to cotton and polyester, did not appear to perform much differently than the other cotton blends. There was also not a significant difference in

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Figure 2.
CMYK Color Comparisons.

Note: Delta E CMYK color comparisons for laundering 5. Sample codes are as follows: 100P (100% polyester), 70V30C (70% viscose from bamboo 30% cotton), 65C35P (65% cotton/35% polyester), 60P30C10R (60% polyester/30% cotton/10% rayon), 60C40P (60% cotton/40% polyester), 50P25C25R (50% polyester/25% cotton/25% rayon), 100C (100% cotton), and 50C50P (50% cotton/50% polyester).

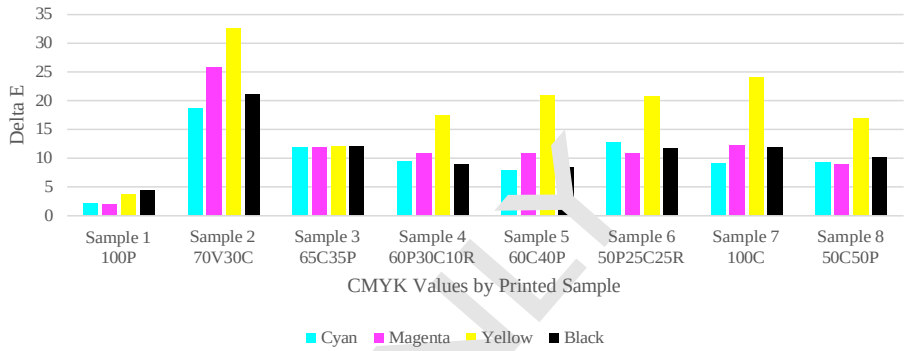

Table 3.
Precise Delta E Readings for Process Color and Printed Sample for Laundering 5.

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
Cyan	2.23	18.68	11.85	9.42	7.99	12.85	9.08	9.36
Magenta	2.03	25.77	11.93	10.87	10.92	10.85	12.34	8.99
Yellow	3.85	32.68	12.09	17.53	20.99	20.85	24.07	17.06
Black	4.46	21.2	12.04	9.05	8.4	11.66	11.85	10.15

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Delta E values based on the amount of cotton or polyester in the fabrics. In laundering 4, Delta E values began to plateau, with the exception of yellow ink. Yellow consistently had the poorest color fastness out of all the inks. Cyan, magenta, and black stayed consistent throughout, with similar reductions in color fastness after each laundering. One wonders then what particular properties of yellow cause it to decrease more rapidly than other process colors with regards to color fastness. Possible explanations include the chemical composition of yellow and its density. Another factor to consider is the manufacturer of the inks. The inks used in this research were Roland B-12 Garment Inks, formulated specifically for white or light-colored textiles. A different set of the same inks or different manufacturer could yield different results. In order to answer this question, additional testing utilizing varying inks would need to be conducted.

Another explanation for the overall color degradation could be due to no application of pretreatment to the fabrics prior to printing. The Roland printer does not require pretreatment for printing, and in general, white fabrics do not need to be pretreated; however, pretreatment is proven to provide more vibrant prints regardless of fabric color. When pretreatment is applied, the ink "sits" on top of the surface of the fabric rather than absorbing into the fabric, resulting in a different appearance and texture.

Figure 3.
Sample 1 (100P).

Note: Photos of prewash versus after five launderings.

Figure 4.
Sample 2 (70V30C).

Note: Photos of prewash versus after five launderings.

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A similar previous study (Bridges, 2024) compared the color fastness of hand-pretreated fabrics, manufacturer-treated fabrics, and untreated fabrics using an Epson Sure Color F2100 DTG printer. This DTG unit prints white ink in addition to CMYK. The results showed that untreated fabrics on 100% cotton had the best color fastness, followed by untreated cotton/polyester blends and manufacturer-treated blends. The hand-pretreated fabrics performed the worst overall. With regards to ink degradation, black performed poorly, while yellow had the least amount of change (Bridges, 2024). These results conflict with results from the current study, which found that cotton fabrics performed among the worst and that the yellow ink had the most significant color change. An obvious explanation for this difference is the DTG printing unit used as well as the difference in inks. Interestingly, the pretreatment did not seem to affect the color fastness as the untreated fabrics performed the best. A future study could test pretreated white textiles on this same printing unit and, again, collect color measurements to determine whether color fastness was improved after laundering.

The fabrics themselves are also important considerations when analyzing color fastness. The polyester could have performed the best due in part to its resistance to chemicals. The low interaction of the fabric with the chemicals used in the ink composition may have resulted in the polyester maintaining better color fastness in comparison to the other textiles tested. In addition, polyester is known to have low absorbency, which results in the ink sitting on top of the surface of the fabric rather than being absorbed into it. The cotton/polyester blends also performed relatively well during testing. This is most likely due to the aforementioned properties of polyester. Future research could examine whether prewashing prior to printing has any impact on color fastness. In addition, the sizing used in fabric manufacturing could have impacted the amount of ink absorption during printing. Domestic laundering using cold water versus hot water along with drying on a lower-temperature heat setting would likely also affect the color fastness. A future study examining different laundering practices would be beneficial to further examine this. Lastly, it would be interesting to test other fabric colors to examine its impact on color fastness and quality.

Limitations that may have impacted the results of this study include the fabric samples themselves. Samples were purchased from a variety of manufacturers and, as previously mentioned, were not laundered prior to printing test targets. In addition, the testing method was based on traditional laundering rather than adhering to ISO or AATCC standards. Finally, prewash Delta E measurements were not taken using the spectrophotometer. This would have been beneficial for comparing the baseline color with the color change after each laundering.

This study is significant in that one goal of this research was to provide fabric recommendations to students when printing t-shirts using the Roland VersaSTUDIO BT-12. The other goal was to make recommendations to manufacturers and consumers regarding untreated fabrics in DTG printing. Based on the data collected in this research, untreated polyester fabrics have better color fastness than other tested fabrics when using this specific printer. The manufacturer of the printer recommends 100% cotton; however, the cotton/polyester blends performed better than 100% cotton based on these findings. These factors may be taken into consideration when using the Roland printer and untreated t-shirt fabrics. Additional research studies focused on both ink and fabric properties as well as pretreatment options should provide more specific recommendations to improve color fastness and quality in DTG printing.

Conclusion

Currently, the DTG printing market is valued at US$810.2 million with an expected growth of 8.2% through the year 2030 (Rationalstat LLC, 2023). As a newer printing technology that is continuing to develop and expand, it is worthwhile to conduct research relevant to improving the technology and its benefits. Print companies are continuing their efforts to create new DTG printing units that have better ink and substrate capabilities while also working to improve supply costs. This study, while narrow in its focus, adds to the limited existing body of research on textiles in DTG printing. Recommendations for manufacturers and consumers, as well as in the educational field, will aid in the continued growth and success of the DTG industry.

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Appendix A

Figure 5.
CMYK Color Comparisons.

Note: Delta E CMYK color comparisons for laundering 2. Sample codes are as follows: 100P (100% polyester), 70V30C (70% viscose from bamboo 30% cotton), 65C35P (65% cotton/35% polyester), 60P30C10R (60% polyester/30% cotton/10% rayon), 60C40P (60% cotton/40% polyester), 50P25C25R (50% polyester/25% cotton/25% rayon), 100C (100% cotton), and 50C50P (50% cotton/50% polyester).

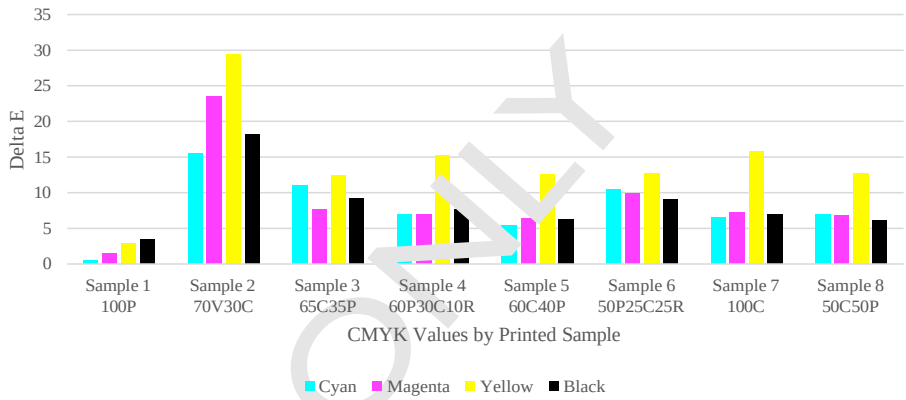

Table 4.
Precise Delta E Readings for Process Color and Printed Sample for Laundering 2.

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample6	Sample7	Sample 8
Cyan	0.46	15.46	10.99	6.97	5.46	10.49	6.57	6.89
Magenta	1.49	23.49	7.69	6.99	6.36	9.91	7.21	6.8
Yellow	2.91	29.34	12.4	15.19	12.61	12.68	15.85	12.74
Black	3.46	18.26	9.22	7.61	6.23	9.11	6.89	6.09

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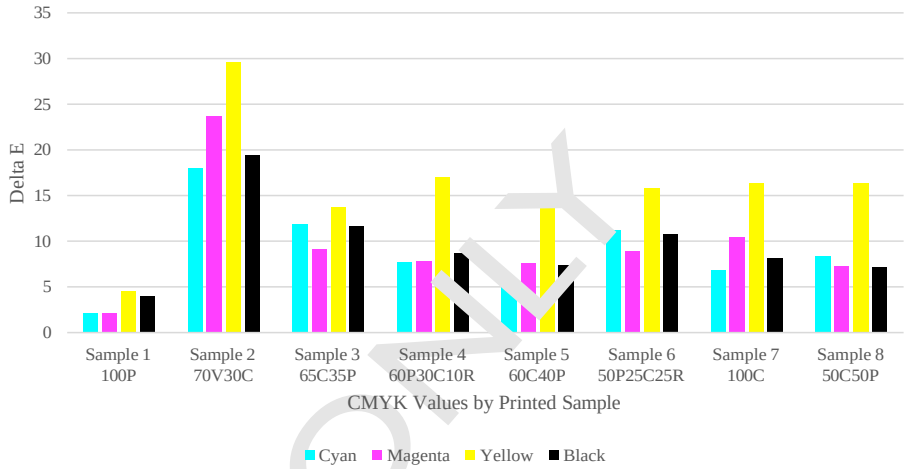
Figure 6.
CMYK Color Comparison.

Note: Delta E CMYK color comparisons for laundering 3. Sample codes are as follows: 100P (100% polyester), 70V30C (70% viscose from bamboo 30% cotton), 65C35P (65% cotton/35% polyester), 60P30C10R (60% polyester/30% cotton/10% rayon), 60C40P (60% cotton/40% polyester), 50P25C25R (50% polyester/25% cotton/25% rayon), 100C (100% cotton), and 50C50P (50% cotton/50% polyester).



PROOF ONLY

Table 5.
Precise Delta E Readings for Process Color and Printed Sample for Laundering 3.

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample6	Sample7	Sample 8
Cyan	2.09	18.05	11.85	7.68	5.61	11.2	6.8	8.32
Magenta	2.11	23.68	9.09	7.76	7.65	8.94	10.42	7.3
Yellow	4.54	29.62	13.78	17.02	14.62	15.78	16.37	16.36
Black	3.97	19.48	11.66	8.67	7.41	10.82	8.16	7.16

Figure 7.
CMYK Color Comparisons.

Note: Delta E CMYK color comparisons for laundering 4. Sample codes are as follows: 100P (100% polyester), 70V30C (70% viscose from bamboo 30% cotton), 65C35P (65% cotton/35% polyester), 60P30C10R (60% polyester/30% cotton/10% rayon), 60C40P (60% cotton/40% polyester), 50P25C25R (50% polyester/25% cotton/25% rayon), 100C (100% cotton), and 50C50P (50% cotton/50% polyester).

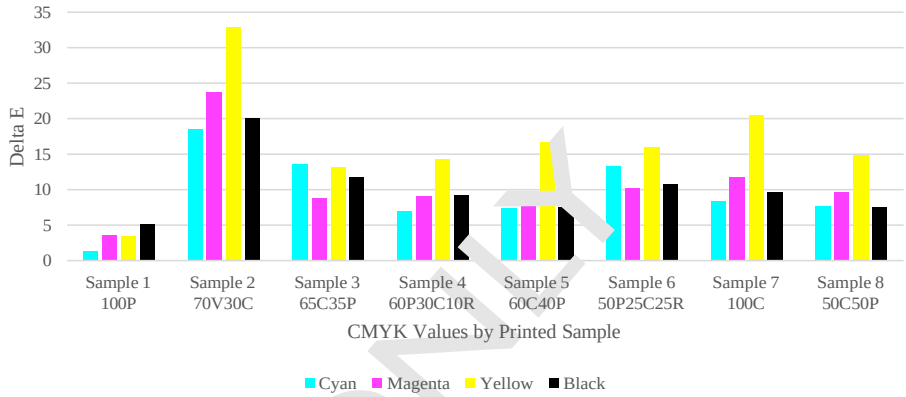


Table 6.
Precise Delta E Readings for Process Color and Printed Sample for Laundering 4.

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample6	Sample7	Sample 8
Cyan	1.32	18.5	13.53	6.93	7.37	13.28	8.4	7.73
Magenta	3.53	23.78	8.85	9.05	7.85	10.19	11.83	9.63
Yellow	3.4	32.88	13.21	14.25	16.7	15.96	20.49	14.86
Black	5.07	20.03	11.73	9.15	7.6	10.83	9.58	7.48

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