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Colorimetric and Lightfastness Assessment of Water-Based Magenta Inkjet Prints on Wood-Free Offset Substrate

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ABSTRACT

This study investigates how the surface coverage of water-based magenta inkjet ink printed on uncoated wood-free offset paper influences its lightfastness under long-term exposure to light. The initial hypothesis of the research is that photodegradative changes in the paper substrate directly modify the colorimetric response of printed patches. Furthermore, it is assumed that an increase in surface coverage will result in a smaller total colour difference (ΔE). Over an 18-month period of simulated exposure inside an accelerated ageing chamber, the photodegradation of prints was monitored using CIE ΔE_{00} colorimetric parameters (ΔE_{00}, ΔC_{00}, ΔL_{00}). Obtained results confirmed the initial hypothesis. The unprinted paper substrate exhibited lower lightfastness compared to the printed patches. Due to pronounced photodegradative yellowing, the paper primarily dictates colorimetric deviations in the light tone domain, resulting in light tonal patches undergoing greater colour change compared to middle and dark tones. However, with increasing surface coverage, the higher concentration of magenta pigment reduces the transmission of radiation to the paper fibres. This diminishes the optical contribution of the degraded substrate to the total reflectance, leading to a general decline in the overall colour difference (ΔE_{00}). A notable exception is observed in the 70% TV patch, which achieves higher stability (lower ΔE_{00}) than the full-tone patch (100% TV). Analysis of individual parameters confirmed that chroma variation (ΔC_{00}) represents the primary factor determining the total colour deviation. Conversely, the effect of lightness variation is negligible, with average ΔL_{00} values remaining up to merely 1.26. By considering the synergy between substrate photodegradation and the optical coverage effect of the applied pigment, this work provides deeper insights into ink–substrate interactions and key factors influencing long-term colour reproduction stability in graphic products.

KEY WORDS
Water-based inkjet, magenta pigment, lightfastness, uncoated offset paper, CIEΔ00, climate chamber

1. Introduction

The digital printing market is experiencing rapid growth, with drop-on-demand inkjet representing one of the most significant and fastest-growing segments of graphic technology. Owing to low operational costs and exceptional adaptability across a wide range of products, inkjet systems hold an increasingly prominent position in the modern graphic arts industry. Although the largest volume continues to stem from continuous web-fed printing (estimated at 500 billion A4 impressions in 2024), sheet-fed inkjet exhibits steady, expansive growth, having reached 60 billion A4 pages. The market for sheet-fed systems in A3, B3,

B2, and B1 formats is currently dominated by smaller-format devices, whereas a drastic increase in installations is projected for larger, more complex systems (B2 and B1) by 2028 (Vujčić et al., 2024; Majnarić et al., 2024a; The Business Research Company, 2024).

In contemporary inkjet production, the implementation of water-based inks is expanding across industrial applications. This market expansion is evidenced by a compound annual growth rate of approximately 5.9%, reflecting a sustained trend towards broader deployment (Narić et al., 2025; The Business Research Company, 2024). The principal advantage of these inks stems from their environmental sustainability, as they contain no volatile organic compounds (VOCs) or residual solvents, reduce odour emissions, and facilitate printhead maintenance by reducing nozzle clogging. Conversely, manufacturers continue to address their primary technological drawbacks, notably slower drying rates, high energy consumption during the fixing process, and reduced adhesion on certain substrates (Jingxiang et al., 2019; Ozcan, Coskun & Arman Kandirmaz, 2024).

In the inkjet printing process, paper—as the most commonly used substrate—substantially impacts both, image formation and the optical durability of the print. Adequate compatibility between the substrate and the ink is governed by the physical and chemical properties of the paper, such as smoothness, surface energy, and absorbency, which directly dictate mechanical dot gain and pigment adhesion (Majnarić et al., 2024b; Narić, 2024; Gazibarić, Stančić & Ružičić, 2024). Beyond physical parameters, the optical properties of the paper (whiteness and brightness) and its chemical composition (the presence of cellulose fibres, lignin, or fluorescent whitening agents) actively participate in degradation reactions under external influences, whereby the substrate directly affects overall colour stability (Kumar, Pathak & Bhardwaj, 2022).

Consequently, evaluating the optical stability of printed material demands a synergistic approach in which the behaviour of the substrate and the ink is considered a unified system exposed to photodegradation, primarily induced by the absorption of ultraviolet photons. In the context of process inks, magenta is particularly susceptible to light-induced chromophore degradation owing to its strong absorption characteristics within the green region of the spectrum. In addition to the pigment itself, the structural components of the paper directly influence the stability of the entire print: while the presence of cellulose with hydrogen bonding and polymer additives containing alkyl groups positively enhances light resistance, polymers incorporated with UV absorbers can destabilise the substrate. Systematic lightfastness analysis is therefore essential for elucidating the mechanisms required to achieve maximum durability in graphic products (Ozcan, Coskun & Arman Kandirmaz, 2024; Lucas, 2001).

Lightfastness testing is conducted under accelerated ageing conditions using chambers basically equipped xenon lights, in compliance with internationally recognised standards, such as ISO 105-B02, ISO 105-B01, ISO 105-B03, ISO 105-B04, ISO 105-B05, ISO 105-B06, ISO 105-B07, ISO 105-B08, and BS ISO 2834 (Boeva et al., 2018; Cofomegra, n.d.; Smithers, n.d.). Objective, reliable evaluation of light-induced changes is attained through spectrophotometric analysis of CIE Lab* parameters and the quantification of total colour difference. To this end, specific colour difference formulae and models are applied, including CMC (l:c), BFD (l:c), CIE 94, LCD, CIE ΔE_{00} and the mathematically refined CIE ΔE_{00} equation (Kašiković, 2015; Aydemir & Yenidoğan, 2018; Milinković et al., 2025).

In accordance with the aforementioned considerations, the objective of this study is to spectrophotometrically assess the impact of accelerated ageing on the lightfastness of prints produced with a water-based magenta inkjet ink, while accounting for the specific characteristics of the applied paper substrate.

2. Methods

To evaluate the printability, tone reproduction stability, and lightfastness performance of water-based inkjet prints on an uncoated paper substrate, a systematic experimental workflow was implemented.

2.1. Materials and printing conditions

Commercial uncoated woodfree offset paper, Mondi Maestro Print 120 g/m² (manufactured from a mixture of dried cellulose, carboxymethyl cellulose, starch, and animal glue), was used as the primary printing substrate. The main technical properties and specifications of the paper substrate are listed in Table 1. Test printing was performed using a water-based inkjet ink formulation designated as IK7125-M magenta, whose technical characteristics and specifications are summarised in Table 2.

A total of 50 samples were produced using the Kyocera TASKalfa Pro 15000c high-speed production inkjet printing machine, integrated with a Fiery PS-50 digital front-end RIP system.

The application of each process colour was carried out by three Kyocera KJ4B-YH piezoelectric printheads (detailed technical specifications of the printing system are outlined in Table 3). Prior to printing the test samples, system calibration and profiling were performed in accordance with the Fogra 52 standard (PSO Uncoated v3 / ISO 12647-2:2013) to ensure tone reproduction accuracy and consistency. For system verification and test printing, the standardised control strip Ugra/Fogra Media Wedge v3.0 was utilized.

Table 1

Mondi Maestro Print 120 g/m² specifications (My Mondi, 2024)

Characteristic	Standard	Value
Basic weight	ISO 536	120 ± 4.5 g/m²
Paper thickness	ISO 536	144 ± 6 µm
Bendtsen roughness	ISO 8791 – 2	225 ± 75 mL/min
Opacity	ISO 2471	96.00 ± 1.6 %
Moisture abs.	ISO 287	6.2 ± 0.7 %
Brightness UV	ISO 2470	135.5 ± 1.5 %
CIE Whiteness	ISO 11 475	145 ± 3.0 %

Table 2

Chemical composition of the Kyocera IK7125-M ink (Kyocera, 2024)

Chemical name	Identifier	Percentage
Water	7732-18-5	40-60%
Polyhydric alcohol	Confidential	20-30%
Triethylene glycol monobutyl	143-22-6	5-10%
Organic pigment	Confidential	5-10%
Glycerol	56-81-5	5-10%
1,2-benzisothiazol-3(2H)-one	2635-33-5	<0.05%
2-methyl-2H-isothiazol-3-one	268-20-4	<0.05%

Table 3

Kyocera TASKalfa Pro 15 000c specifications (Kyocera, n.d.)

Paper size	98 x 148 mm – 330.2 x 488 mm
Print speed	A4: 150 ppm/150 ppm (75 sheets)
	A3: 88 ppm/88 ppm (44 sheets)
	SRA3: 75 ppm/75 ppm (37 sheets)
	A3W: 74 ppm/74 ppm (37 sheets)
Available thickness printing at rated speed	Up to 360 g/m²
Print resolution	600 x 600 dpi, 600 x 1200 dpi

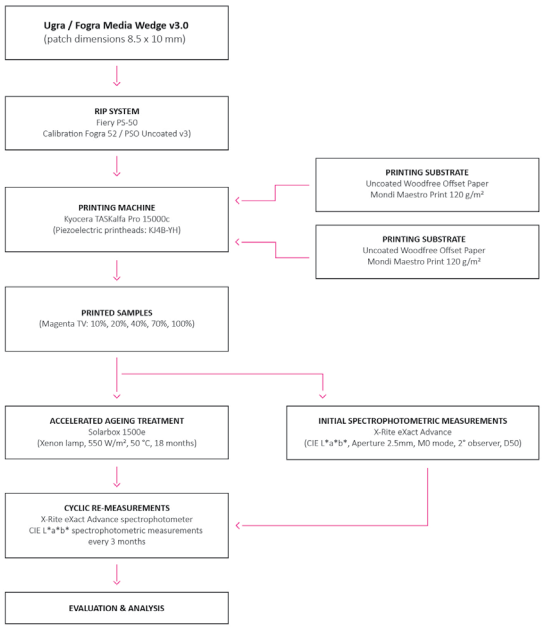
2.2. Spectrophotometric measurements

Evaluation of colour differences were performed by measuring CIE L*a*b* values using an X-Rite eXact Advance spectrophotometer. Although the printed control strip contains a comprehensive set of measurement fields, specific magenta patches were selected for lightfastness testing across the tonal range, representing light tones, midtones, and dark tones at tone value (TV) coverages of 10%, 20%, 40%, 70%, and 100%.Measurements were carried out under standardised geometric and optical conditions: a 2.5 mm measuring aperture, M0 measurement mode (unfiltered standard illumination in accordance with ISO 13655), 2° standard observer, and D50 standard illuminant.

2.3. Lightfastness testing

Lightfastness testing of the prints was performed in a Solarbox 1500e accelerated ageing chamber equipped with a full-spectrum xenon lamp to evaluate pigment stability and substrate degradation under light exposure. The exposure parameters were set to an irradiance of 550 W/m² (without a UV filter), a chamber temperature of 50 °C, and a total exposure duration equivalent to 18 months of natural ageing. To monitor photodegradation's influence, samples were periodically removed from the chamber at 3-month simulated ageing intervals for control CIE L*a*b* spectrophotometric re-measurements of the selected patches.

A schematic representation of the performed experimental methodology is shown in Figure 1.

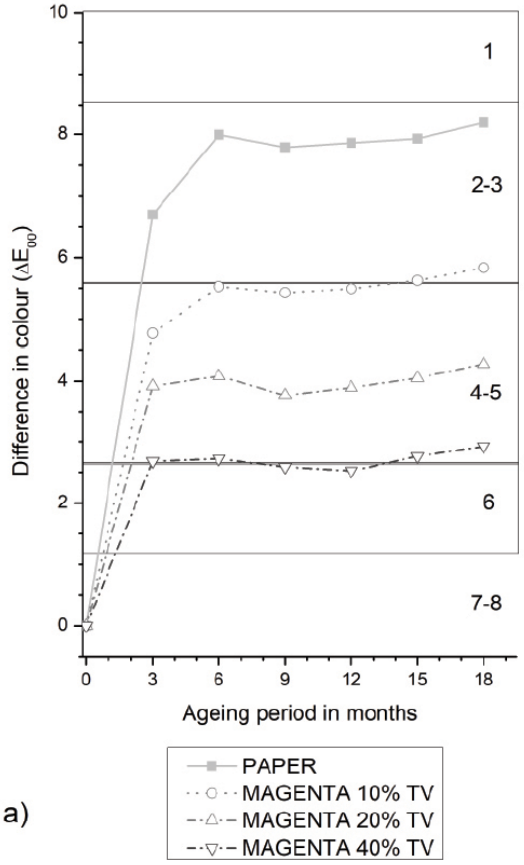


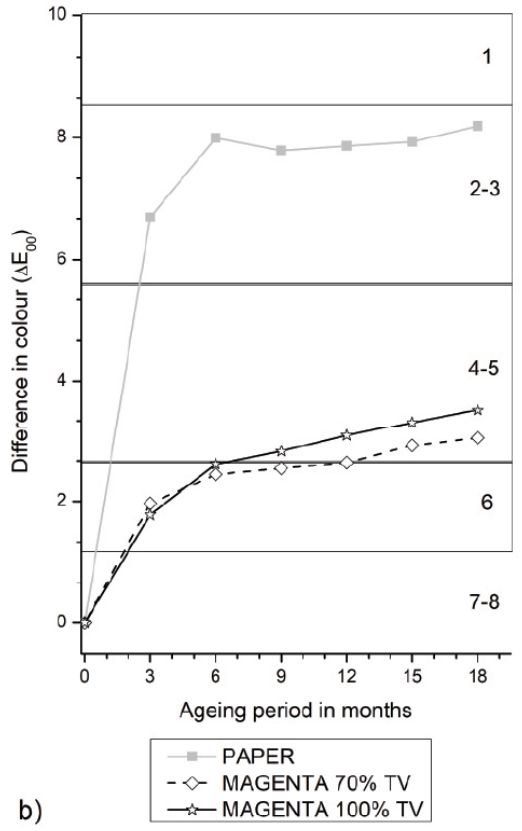
» **Figure 1:** *Schematic representation of the performed experiment*

3. Results

This section presents the spectrophotometric measurement results for the unprinted paper substrate alongside the light tones (10% and 20% TV), midtones (40% TV), and dark tones (70% and 100% TV) of the magenta patches subjected to 18 months of accelerated ageing under controlled conditions (50 °C, 550 W/m²).

The evaluation includes the total colour difference (ΔE_{00}), chroma deviation (ΔC_{00}), and lightness deviation (ΔL_{00}). The total colour difference (ΔE_{00}) for the paper substrate and the magenta printed patches over the 18-month ageing period is illustrated in Figure 2.





» **Figure 2:** *Colour difference diagram of light and mid-tones (a), Colour difference diagram of dark tones (b)*

The unprinted paper substrate demonstrated the most pronounced increase during the initial 3 months of exposure, reaching a value of ΔE_{3m} = 6.70. After 6 months of treatment, the value increased to ΔE_{6m} = 7.99, following which the total colour difference stabilised at an average value of $\Delta E_{6\text{-}18m}$ = 7.95 for the duration of the testing period.

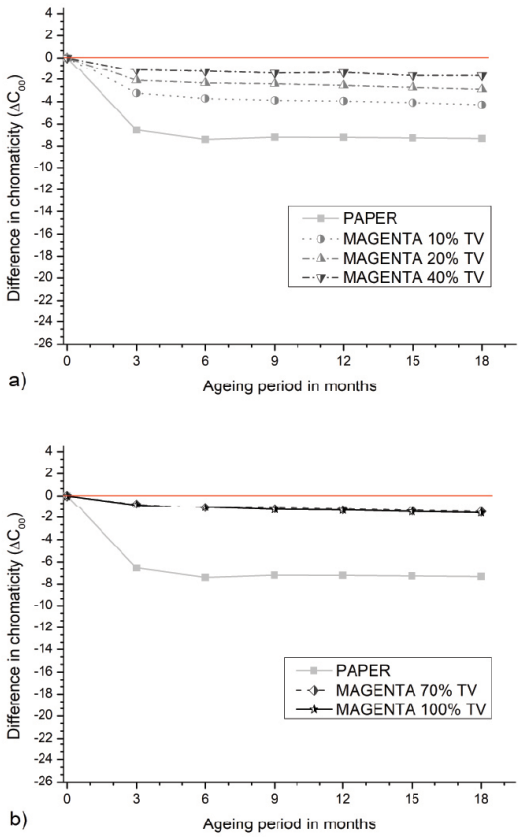
For the magenta printed patches, the 10% TV patch demonstrated a colour difference of ΔE_{6m} = 5.53 after 6 months, maintaining an average value of $\Delta E_{6\text{-}18m}$ = 5.58 through the 6-to-18-month interval. The 20% TV patch displayed a mean total colour difference of $\Delta E_{3\text{-}18m}$ = 4.00 across the 3-to-18-month period, attaining ΔE_{18m} = 4.28 at the 18-month mark. The 40% TV patch maintained an average colour difference of $\Delta E_{3\text{-}18m}$ = 2.70. For the dark tones, measurable changes occurred after 9 months, establishing average values of $\Delta E_{3\text{-}18m}$ = 2.59 for the 70% TV patch and $\Delta E_{3\text{-}18m}$ = 2.85 for the 100% TV patch.

In terms of chroma deviations (ΔC_{00}), shown in Figure 3, the paper substrate displayed an initial decrease of $\Delta C_{0\text{-}3m}$=-6.56 within the first 3 months, stabilising at an average value of $\Delta C_{6\text{-}18m}$ =-7.29 from 6 to 18 months. All printed magenta patches presented strictly negative ΔC_{00} values. For the 10% TV patch, an overall mean chroma deviation of $\Delta C_{3\text{-}18m}$ =-4.17 was attained across the 3-to-18-month interval.

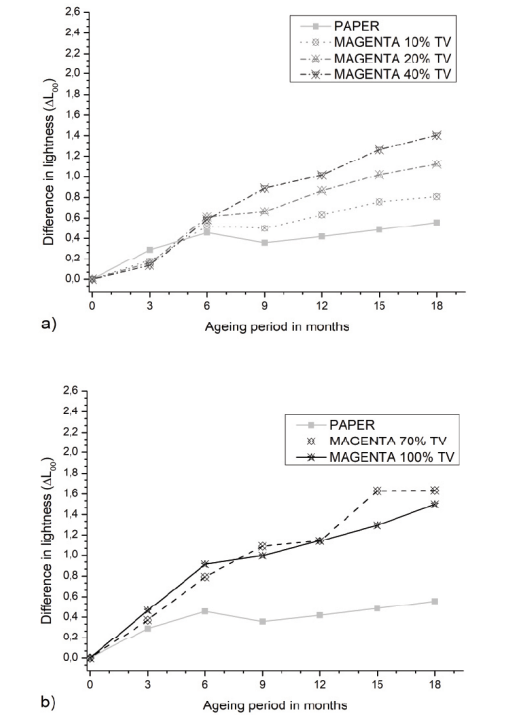
For the 20% TV patch, the chroma deviation progressed from ΔC_{3m} =-2.10 at 3 months to ΔC_{18m} =-2.91 at 18 months, with an overall mean quantified at $\Delta C_{3\text{-}18m}$ = -2.51. The 40% TV patch showed values of ΔC_{3m} =-1.18$ and ΔC_{18m} =-1.69, averaging $\Delta C_{3\text{-}18m}$ =-1.46. The dark tone patches generated initial 3-month deviations of ΔC_{3m}=-0.77 (70% TV) and ΔC_{3m}=-0.82 (100% TV), which expanded to ΔC_{18m}=-1.51 (70% TV) and ΔC_{18m}=-1.61(100% TV) after 18 months, corresponding to period averages of $\Delta C_{3\text{-}18m}$=-1.20 and $\Delta C_{3\text{-}18m}$=-1.28, respectively.

Regarding lightness deviations (ΔL_{00}), presented in Figure 4, the paper substrate registered a mean deviation of $\Delta L_{3\text{-}18m}$= 0.50 across the 3-to-18-month period. For the light tones and midtones (10%, 20%, and 40% TV), the lightness deviation averaged approximately 0.57 during the initial 6 months.

In the subsequent interval (6 to 18 months), the average lightness deviations were determined as $\Delta L_{6\text{-}18m}$= 0.64 for the 10% TV patch, $\Delta L_{6\text{-}18m}$= 0.85 for the 20% TV patch, and $\Delta L_{6\text{-}18m}$ = 1.03 for the 40% TV patch. The dark tone patches displayed 6-month values of ΔL_{6m}= 0.79 (70% TV) and ΔL_{6m}= 0.91 (100% TV). Over the 6-to-18-month timeframe, the 70% TV patch reached a mean value of $\Delta L_{6\text{-}18m}$= 1.26, attaining a maximum deviation at the 15th month prior to stabilisation, whereas the 100% TV full-tone patch manifested an average deviation of $\Delta L_{6\text{-}18m}$= 1.17 with a continuous upward trend.



» **Figure 3:** *Diagram of changes in chromaticity of light and mid-tones (a), Diagram of changes in chromaticity of dark tones (b)*



» **Figure 4:** *Diagram of changes in lightness of light and mid-tones (a), Diagram of changes in lightness of dark tones (b)*

4. Discussion

The spectrophotometric evaluation over 18 months of accelerated ageing reveals distinct degradation behaviours between the unprinted paper substrate and the water-based magenta inkjet prints across varying tone value coverages. The paper substrate demonstrated high sensitivity to light exposure, undergoing its most severe degradation during the initial 3 months. The stabilisation of the total colour difference confirms the presence of clearly visible colour changes on the substrate.

This degradation is primarily associated with an increased influence of chroma, causing a permanent hue variation of the substrate toward a yellow-red region. Conversely, the minimal lightness deviations indicate that lightness changes have a minor contribution to the overall colour difference of the paper substrate compared to the chromaticity variation.

The lightfastness of the magenta prints is directly proportional to surface coverage (TV). In light tones such as the 10% TV patch, colour differences stabilise after 3 months; despite maintaining a classification of very good lightfastness, this coverage demonstrates the highest overall deviation among all printed samples. Increasing coverage to 20% TV brings the print within the threshold of excellent lightfastness (ΔE_{00}= 4.00), exceeding this boundary only slightly at the 18-month mark. Midtones (40% TV) and dark tones (70% and 100% TV) maintain high lightfastness stability, with minor variations appearing only after 9 months. The performance of the 70% TV and 100% TV patches is nearly identical, with the 70% TV patch showing marginally higher stability ($\Delta E_{3\text{-}18m}$ = 2.59).

Analyzing individual colour components—specifically chroma (ΔC_{00}) and lightness (ΔL_{00}) variations—reveals different degradation mechanisms across various tonal coverages. The ΔC_{00} values across all printed patches confirm that changes in chromaticity is the primary cause of total colour difference. Increasing tone value coverage directly reduces this change: transitioning from 10% to 20% TV reduces average chroma variation by 1.35, while advancing to 40% TV provides an additional reduction of 1.05.

In dark tones, changes in chromaticity becomes minimal, confirming that higher pigment density effectively protects the printed layer against saturation loss. In contrast, lightness deviations display an inverse trend during later stages of ageing (6 to 18 months). While light tones (10% TV) preserve relatively stable, full-tone prints (100% TV) experience higher and continually rising lightness values.

This suggests that in full-tone areas, where chroma remains highly stable, lightness alteration becomes an increasingly prominent contributor to ongoing visual colour changes under prolonged exposure.

5. Conclusions

This study provided a comprehensive evaluation of the lightfastness and degradation behaviour of water-based magenta inkjet ink printed on a wood-free offset paper substrate subjected to an 18-month exposure period inside an accelerated ageing chamber. The results confirm that overall print stability is directly determined by tone value coverage, alongside the complex interaction between the pigment layer and the paper substrate. Given that the paper substrate itself undergoes notable colorimetric changes, its influence on the visual degradation of the magenta patches is particularly pronounced in light tonal values (10% and 20% TV), while midtones and dark tones show considerably higher stability.

The unprinted substrate demonstrated high sensitivity to light exposure, achieving a total colour difference of $\Delta E_{6\text{-}18m}$= 7.95 associated with an increased influence of chroma ($\Delta C_{0\text{-}3m}$=-6.56). Increasing surface coverage yielded a clear reduction in total colour difference and chroma change. Increasing surface coverage directly reduces total colour differences and changes in chromaticity, allowing midtones (40% TV) and dark tones (70% and 100% TV) to maintain high stability within the boundaries of excellent lightfastness.

Evaluation of individual colour components demonstrates that chromaticity variation represents the primary cause of total colour difference across all printed patches throughout the entire exposure period. In contrast, lightness alterations exert a minor overall influence; although slightly higher lightness variations appear in dark tones, these values remain low, reaching maximum deviations of ΔL_{18m}= 1.63 for the 70% TV patch at the 18-month mark.

These findings provide valuable insights for evaluating the long-term stability and colour accuracy of water-based inkjet prints on uncoated offset substrates in professional graphic applications. To build upon these insights, future research should expand toward evaluating ink-substrate interaction mechanisms across diverse non-absorbent and coated substrates. Furthermore, investigating the application of protective overprint varnishes, UV-curable coatings, and surface laminates presents a crucial direction for mitigating substrate-induced yellowing and suppressing late-stage lightness alterations in full-tone areas.

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