Digital inkjet printing quality assessment affected by topographical and morphological elements of the fabric surface structure

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Received: January 20, 2025
Accepted: March 15, 2025
UDC 677.016.4:677.057.5

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Original scientific paper**

This study investigates the influence of fabric structure and surface topography on colour reproduction and the quality of digital inkjet printing with reactive inks. The study was conducted on three 100% cotton fabrics made from identical yarns and with the same warp and weft densities, but differing in weave structure: plain weave 1/1, twill 2/1, and mixed panama 2/1. Following appropriate pretreatment, the samples were digitally printed using a Mimaki Tx2-1600 printer. Spectrophotometric, image, visual, and microscopic analyses were applied to evaluate the influence of fabric structure. Spectrophotometric measurements revealed differences in the spectral and colorimetric characteristics of the same colours reproduced on fabrics with different structures. The calculated ΔE values between structurally different samples exceeded the defined acceptance threshold (ΔE* = 2). Image analysis of a printed line with a nominal width of 1.00 mm revealed differences in the area and perimeter of the printed element, indicating different degrees of lateral ink spreading and reproduction regularity. The lowest area and perimeter values were obtained for the plain weave 1/1 fabric, while the highest values were obtained for the mixed panama 2/1 fabric. Visual and microscopic analyses of the photographic print further revealed differences in the reproduction of image details associated with fabric surface structure. Overall, the results demonstrate that the structure and surface topography of the textile substrate play an important role in colour reproduction, the accuracy of graphic element reproduction, and the overall quality of digital inkjet printing.*

Keywords: *Fabric topography; colour reproduction; digital inkjet printing; image analysis; ImageJ*

Izvorni znanstveni rad**

Ocjena kvalitete digitalnog inkjet tiska pod utjecajem topografskih i morfoloških elemenata površinske strukture tkanine

U radu je istražen utjecaj strukture i površinske topografije tkanine na reprodukciju boje i kvalitetu digitalnog inkjet otiska reaktivnim tiskarskim bojama. Istraživanje je provedeno na trima 100 % pamučnim tkaninama izrađenima od identične pređe i jednake gustoće osnove i potke, ali različitih vezova: platno 1/1, keper 2/1 i miješana panama 2/1. Nakon odgovarajuće predobrade uzorci su digitalno otisnuti na uređaju Mimaki Tx2-1600. Za vrednovanje utjecaja strukture tkanine primijenjene su spektrofotometrijska, slikovna te vizualna i mikroskopska analiza. Spektrofotometrijskim mjerenjima utvrđene su razlike u spektralnim i kolorimetrijskim svojstvima istih boja reproduciranih na strukturno različitim tkaninama. Slikovnom analizom otisnute linije nominalne širine 1,00 mm utvrđene su razlike u površini i perimetru otisnutog elementa, koje upućuju na različit stupanj lateralnog širenja tiskarske boje i pravilnosti reprodukcije. Najmanje vrijednosti površine i perimetra utvrđene su na tkanini u platnenom vezu 1/1, a najveće na miješanoj panami 2/1. Vizualna i mikroskopska analiza fotografskog otiska dodatno su pokazale razlike u reprodukciji detalja povezane s površinskom strukturom tkanine. Rezultati potvrđuju da struktura i topografija tekstilne podloge imaju važnu ulogu u reprodukciji boje, preciznosti reprodukcije grafičkih elemenata i ukupnoj kvaliteti digitalnog inkjet otiska.

Ključne riječi: *Topografija tkanine; reprodukcija boja; digitalni inkjet tisak; slikovna analiza; ImageJ*

**Paper presented at the *17th Scientific-Professional Symposium Textile Science and Economy*, Jan 28, 2025, Zagreb, Croatia

1. Introduction

The structure of the fabric, which is determined by the construction parameters of the yarn, the weave, the yarn density in the warp and weft direction, and the yarn count, largely controls the texture and surface topography of fabrics [1,2]. The complexity and inhomogeneity of textile materials affect their surface properties and consequently strongly influence droplet shape, and spreading speed [3,4]. In the case of ink droplets, the arrangement and distribution of capillaries in the fabric structure have a direct effect on the spread of the ink on the surface of the fabric [5]. There are several studies in the literature in which the direct dependence of the colour appearance of the textile surface on its topographical and morphological properties is investigated [6–10]. These studies confirm the significant influence of texture on the visual perception of colour as well as on the results of instrumental evaluation. It was also found that the properties of the yarn surface play a greater role in determining the quality of inkjet printing than the parameters of fabric construction [11].

The aim of this work is to investigate the influence of different structural characteristics of textiles on the colour appearance of digitally printed textile substrates, to monitor the quality of color reproduction, and to analyze the behavior of reactive ink on textile substrates. In order to contribute to the understanding of the effects of fabric structure and yarn properties on colour reproduction and image quality, as well as the complexity of the interactions between fabric and colour, three methods were used to analyze three different images produced with digital inkjet printing technology on three different fabric substrates. Three different images, namely: a multicoloured composition, created in the Adobe Illustrator program; a photograph standardized for image analysis, downloaded from FOGRA – the research institute for the printing and media industry; and a print quality analysis form, containing various geometric elements, were digitally printed on three fabrics with different structures and textures: Plain weave 1/1, Twill weave 2/1, and Mixed panama 2/1. Three different methods were used for the digitally printed images analysis. The first method analyses colour reproduction using spectrophotometric measurements to obtain data on colour properties. Second method – method of image analysis together with microscopic imaging of the samples was used to obtain the data on the ink capillarity / wicking on different fabrics (when analysing chosen geometric form). Third method refers to the visual/subjective analysis of the photograph printed on different fabrics.

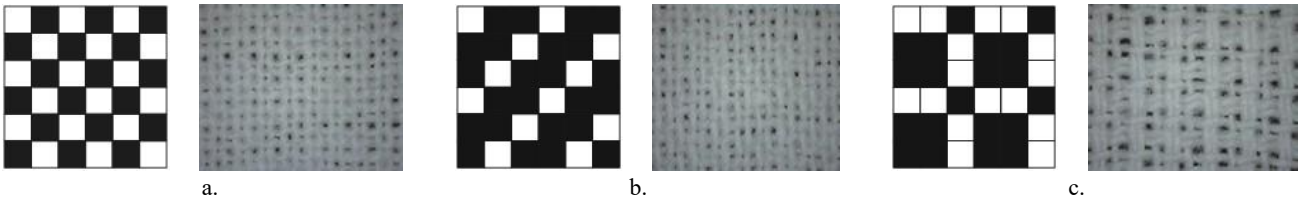
2. Materials and Methods

To provide a better understanding of the relationship between fabric structure and colour reproduction, three fabrics with different weave structures but the same thread density were compared. The fabrics selected for the analysis were manufactured by Čateks d.d. All fabrics were made of 100% cotton using identical yarns, while differing in their constructional characteristics, resulting in different surface structures and textures: plain weave 1/1 (Sample 1), twill 2/1 (Sample 2), and mixed panama 2/1 (Sample 3). The structural parameters of the fabrics are presented in Table 1. Schematic representations of the weave structures and microscopic images of the corresponding fabric surfaces are shown in Fig.1.

Three different images were created to analyse the colour rendering. A multicoloured composition created in Adobe Illustrator and printed on Sample 1, which was chosen as the standard, is shown in Fig.2. In addition to the design of the sample and the representation of the printed image on Sample 1 (Plain weave 1/1), Fig.2b shows the colours Green 1 and Red 2, which were selected from the multicoloured composition for further colour analysis.

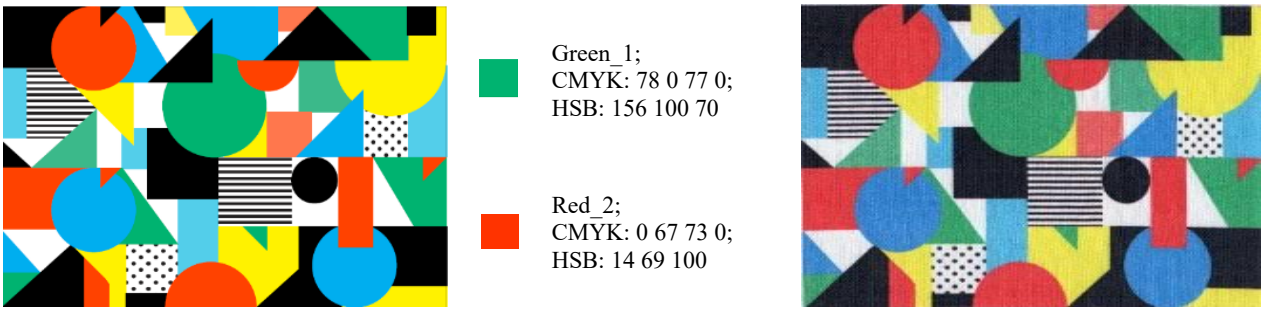
Tab.1 Structural parameters of selected fabrics

Sample - Weave	Warp fineness [tex]	Weft fineness [tex]	Warp density [threads/cm]	Weft density [threads/cm]	Mass per unit area [g/m^2]
1 - Plain weave 1/1	36	36	24	24	171
2 - Twill weave 2/1	36	36	24	24	173
3 - Mixed panama 2/1	36	36	24	24	173



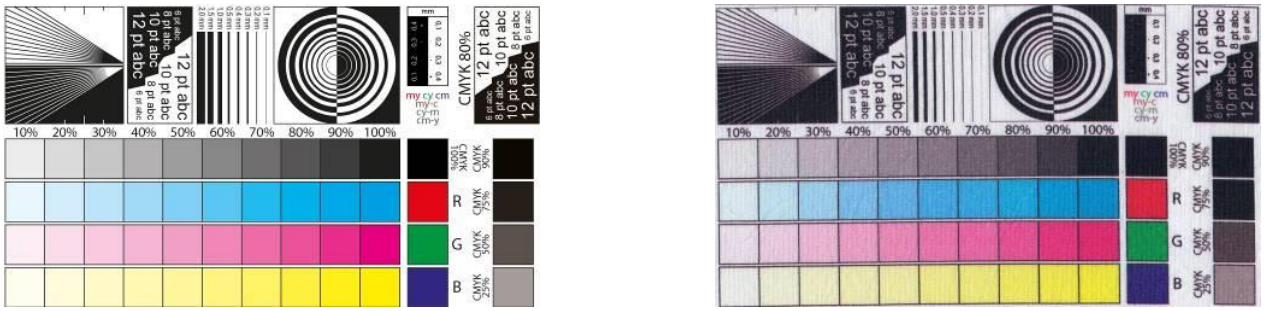
a. b. c.

Fig.1 Construction weaves and microscopic images of selected fabrics: a. Sample 1, b. Sample 2, c. Sample 3



a. b. c.

Fig.2 Multicoloured composition: a. Composition created in Adobe Illustrator, b. Colours selected for objective analysis, c. Composition printed and scanned on Sample 1 (standard)



a. b.

Fig.3 Print quality analysis form: a. Digital image of the form, b. Scan of the Print quality analysis form printed on Sample 1 (standard)



a. b.

Fig.4 Photograph used for evaluation of image quality: a. Photograph in digital form from FOGRA website, b. Scan of the photograph printed on Sample 1 (standard)

Fig.3 shows a Print quality analysis form used for print quality evaluation, and Fig.4 shows a photograph downloaded from the FOGRA website used for testing and evaluating the image quality printed on different textile structures.

Three different images were printed on selected fabrics using the Mimaki Tx2-1600 digital printer with reactive inks. Before printing, the samples were pre-treated with a solution of thickener and alkali to ensure the reaction of the dye with the cellulose fibre and to prevent the effect of capillary forces and thus the spilling of ink. After printing, the samples were air-dried and then fixed by steaming for 30 minutes. After fixing, the samples were washed in the following steps:

1. Initial rinsing with cold water.
2. Rinsing with hot water (55 °C) until the capillary spread of the dye stops.
3. Washing in boiling water (100 °C) with the addition of 0.5 g/L soaping agent Cotoblanc NSR (CHT-Bezema).
4. Final rinsing with cold water.
5. Machine washing for 35 minutes at a temperature of 40 °C, in order to remove unfixed dye.

After washing, the samples were air-dried in order to preserve the structural properties of the fabric and enable further analysis of the colouristic characteristics of the print.

Three different methods were used to analyse three different images printed on special textile substrates.

Method 1. Spectrophotometric measurements were performed to evaluate colour reproduction. Green 1 and Red 2 were selected from the multicoloured composition for further analysis. The spectral characteristics were measured using a Datacolor 850 reflectance spectrophotometer under standard illuminant D65 and d/8° measurement geometry. The "measure until tolerance" function was applied, requiring a minimum of 10 measurements, with the results accepted when the total colour difference between individual measurements was less than 0.1 ($\Delta E^* < 0.1$). Spectrophotometric analysis of the printed samples was performed according to EN ISO 105-J01:1999, *Textiles – Tests for colour fastness – Part J01: General principles for measurement of surface colour*. Colour strength (K/S) and CIELab* parameters were calculated from the measured reflectance and tristimulus values and compared among the samples.

Method 2. Image analysis was used to evaluate the sharpness of selected printed graphic elements and the spreading of the printing ink on fabrics with different structural characteristics. The geometric element designated as 1.00 mm Line from the print quality assessment test form was selected for analysis. The printed element was captured using a Dino-Lite digital microscope, and the resulting microscopic images were analysed using ImageJ software. The analysis provided parameters for comparing the quality of line reproduction on the different fabrics. The width of the printed line and its deviation from the nominal width of 1.00 mm were determined in ImageJ, providing an assessment of printing ink spreading and reproduction accuracy on fabrics with different structures. The images of the geometric element Line 1.00 mm were converted into binary images by the following steps:

File – Open – Document (Microscopic images of the samples)

Microscopic images are cropped to the same size

Image Type – 8 bit

Process – Binary – Make Binary

Analyse – Set Measurements (Area, Perimeter)

Wand (Tracing tool) is used to trace the measured area, i.e. the Line 1.00 mm

Analyse – Measure.

According to Mhetre, studies investigating the influence of fabric structure on the quality of inkjet printing mainly use the objective means of print quality (PQ) assessment developed by ISO (International Organization for Standardisation, PQ standards ISO/IEC 13660 200 / CE) [11]. These standards were originally developed for printing on paper, but are also frequently used for assessing the inkjet print quality of textiles. Important quality attribute for PQ assessment, for an element, such as line width and edge sharpness were analysed in this research. Additionally, the CMYK and RGB values from the PQ analysis form were measured with the Datacolor 850 reflectance spectrophotometer to determine the colour gamut in a*/b* colour space.

Method 3. The phototograph downloaded from FOGRA website [12] and printed on the different textile substrates was analysed; chosen segments of the photograph were determined for the visual/ subjective analysis to evaluate colour reproduction and image quality.

3. Results and Discussion

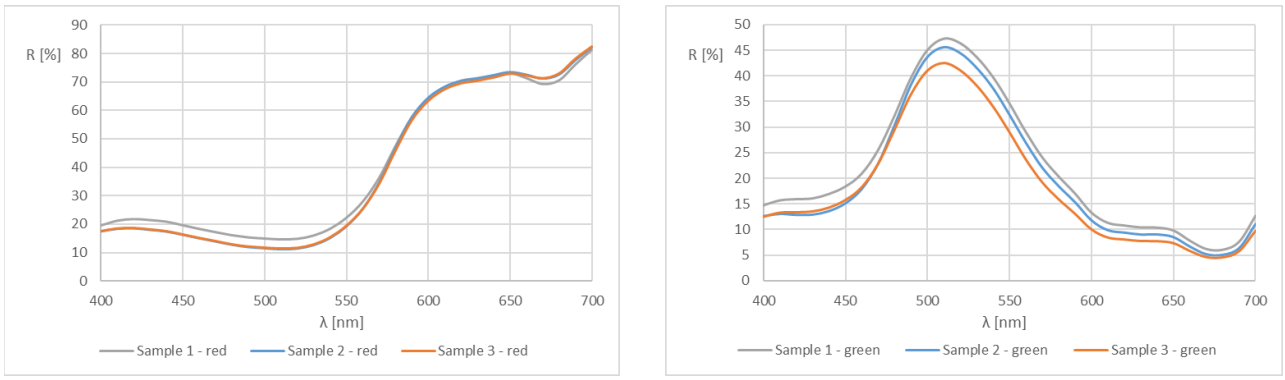
The results were evaluated with respect to the influence of the structural and surface characteristics of the fabrics on colour reproduction and digital inkjet print quality. The findings are presented and discussed according to the individual aspects of print quality assessment.

3.1. Multicoloured composition

The reflectance curves and colour strength (K/S) values for Green 1 and Red 2 on Samples 1–3 are presented in Fig.5 and Fig.6a.

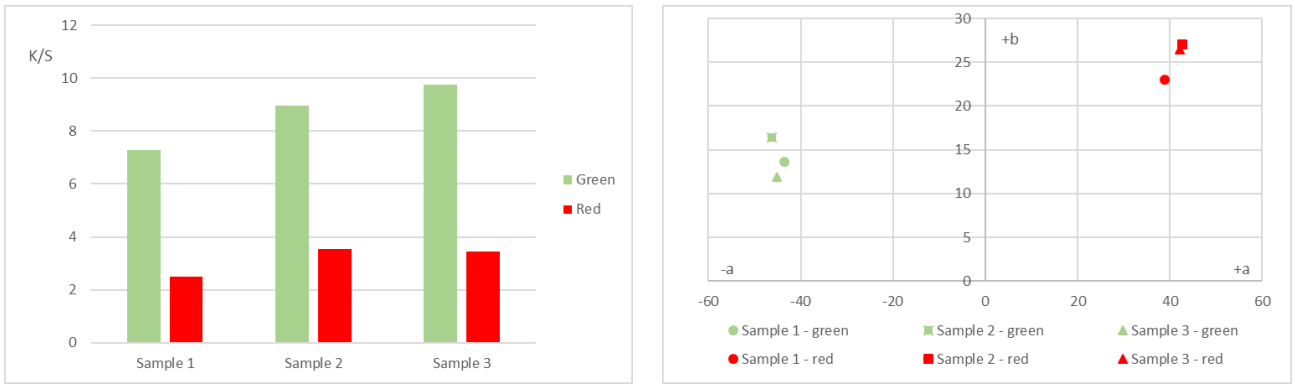
The reflectance curves of the red-printed samples (Fig.5a) show a maximum reflectance at approximately 650 nm. The curves of Samples 2 and 3 almost completely overlap, indicating very similar spectral characteristics of the reproduced red colour, whereas Sample 1 exhibits slightly higher reflectance in certain regions of the visible spectrum.

For the green-printed samples (Fig.5b), the maximum reflectance occurs at approximately 510 nm, with more pronounced differences between the spectral curves than those observed for the red-printed samples. Sample 1 exhibits higher overall reflectance and a slight shift in the position of the curve maximum compared with Samples 2 and 3. The differences in the spectral characteristics of the prints are consistent with the K/S values presented in Fig.6a. For Green 1, the highest K/S value was obtained for Sample 3 and the lowest for Sample 1, indicating higher and lower colour strength, respectively. For Red 2, the K/S values are generally lower than those obtained for Green 1; Samples 2 and 3 show very similar values, while the lowest K/S value was obtained for Sample 1.



a. b.

Fig.5 Remission curves of a. red and b. green colour on Samples 1-3



a. b.

Fig.6 a. Colour depth of red and green colour on Samples 1-3; b. Colour coordinates of red and green colour on Samples 1-3

Since the same printing ink was applied to all samples, differences in reflectance intensity and in the shape of the reflectance curves indicate the influence of fabric structure and surface topography on the interaction of incident light with the coloured textile surface. Differences in the arrangement of interlacing points and yarn floats alter the surface geometry and, consequently, the way light is reflected. As a result, the same printing ink applied to fabrics with different structures does not produce identical spectral characteristics and, consequently, does not result in an identical colour appearance. Fig.6b shows the positions of the red- and green-printed Samples 1–3 in the a/b plane of the CIELAB colour space.

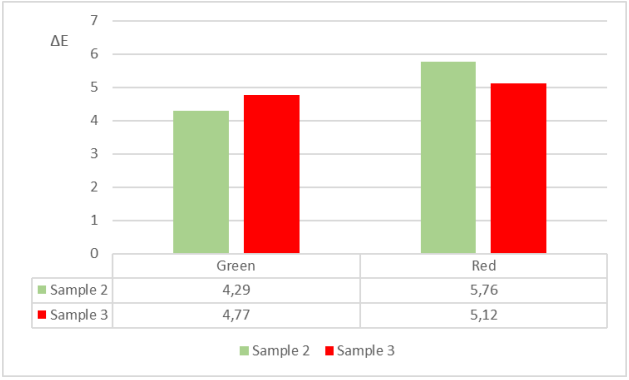


Fig.7 Colour difference of red and green colour on Samples 2 and 3 compared to the Sample 1

For Red 2, the positions of Samples 2 and 3 almost overlap, which is consistent with their very similar reflectance curves, whereas Sample 1 is positioned slightly closer to the achromatic axis. For Green 1, the differences between the sample positions are more pronounced: Sample 2 is shifted towards the yellow region, whereas Sample 3 is positioned further towards the green region of the CIELAB colour space. Fig.7 presents the total colour differences (ΔE) for the red- and green-printed Samples 2 and 3 relative to the reference Sample 1. The obtained ΔE values exceed the defined acceptance threshold of $\Delta E^* < 2$, indicating that differences in fabric structure result in differences in the reproduction of the same colour. The largest colour difference was obtained for Red 2 on Sample 2 ($\Delta E^* = 5.76$), while the smallest, although still above the defined acceptance threshold, was obtained for Green 1 on Sample 2 ($\Delta E^* = 4.29$).

3.2. Statistical method of image analysis on print quality analysis form and colour gamut defining

The 1.00 mm Line element was used for image analysis, while the CMYK and RGB colour patches printed on all three samples were measured using a reflectance spectrophotometer to determine the colour gamut (Fig.8).



Fig.8 Element Line 1.00 mm marked for image analysis; CMYK and RGB values measured for colour gamut defining

The positions of the measured RGB and CMYK colour patches for Samples 1–3 in the a/b plane of the CIELAB colour space are presented in Fig.9, defining the colour gamut of each sample. The most pronounced differences among the three samples are observed for magenta, red, yellow, and green, whereas cyan and blue show smaller differences. These results further demonstrate that fabric surface structure affects colour reproduction and that the magnitude of this effect depends on the reproduced colour.

Microscopic images of the line with a nominal width of 1.00 mm printed on Samples 1–3 are shown in Fig.10, while the corresponding binary images used for image analysis are presented in Fig.11. The microscopic images already reveal the influence of fabric surface structure on the shape and edge regularity of the printed line, while the image analysis results (Table 2) enable a quantitative comparison of its area and perimeter. The lowest area (8.7780 mm²) and perimeter (52.5819 mm) values were obtained for Sample 1 (plain weave 1/1). Both values increase for Sample 2 (twill 2/1) and reach their highest levels for Sample 3 (mixed panama 2/1). The increase in the area of the printed element indicates more pronounced spreading of the printing ink beyond the intended boundaries of the line, while the increase in perimeter reflects greater edge irregularity.

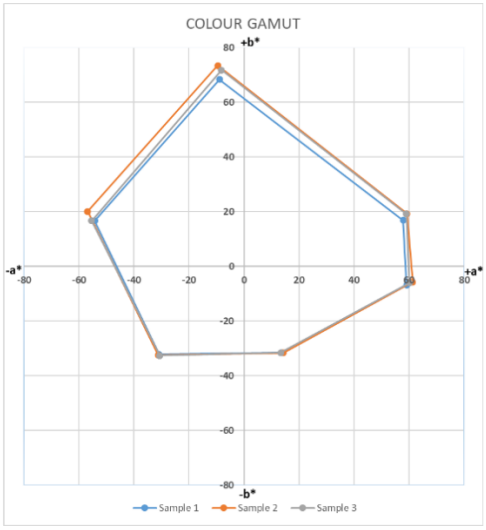


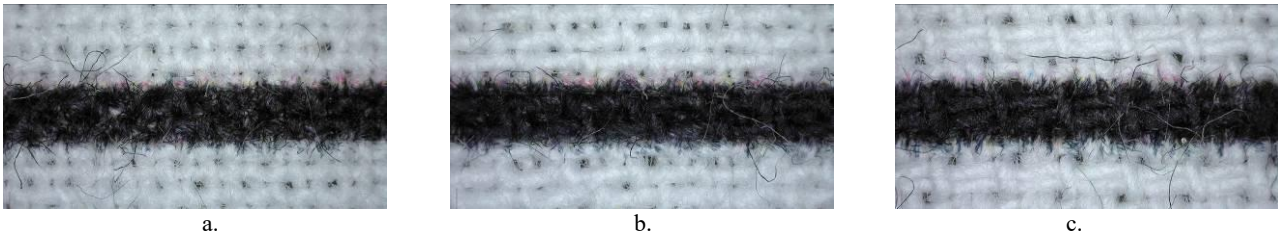
Fig.9 Colour gamut defined by CMYK and RGB values in a*/b* colour space for Sample 1, 2 and 3

These results therefore demonstrate that fabric structure and surface topography directly affect the geometric accuracy of the reproduced printed element.

Tab.2 Image Analysis results

Samples	Area [mm²]	Perimeter [mm]
Sample 1	8.7780	52.5819
Sample 2	9.2881	57.0747
Sample 3	9.4627	62.6039

The most pronounced differences were observed between the plain weave 1/1 and mixed panama 2/1 fabrics. The higher number of interlacing points in the plain weave results in a more compact and uniform surface structure, which limits the lateral spreading of the printing ink and enables more accurate reproduction of the printed line.



a. b. c.

Fig.10 Cropped Dino-Lite microscopic images of the element Line 1.0 mm for the analysis on: a. Sample 1, b. Sample 2 and c. Sample 3, magnification of 53.2x



a. b. c.

Fig.11 Binary image of the element Line 1.00 mm on: a. Sample 1, b. Sample 2 and c. Sample 3 for image analysis in ImageJ program

In contrast, longer yarn floats and fewer interlacing points in the twill 2/1, and particularly in the mixed panama 2/1, result in greater surface heterogeneity, promoting more irregular spreading of the printing ink along the yarn structure.
Consequently, both the area and perimeter of the printed line increase, while its contour becomes less regular. The results confirm that fabric construction, through its influence on surface structure and topography, significantly affects the accuracy of graphic element reproduction and the overall quality of digital inkjet printing.

3.3. Visual / subjective analysis of the photograph

Fig.12 shows selected segments of the photograph printed on Samples 1–3, while the same segments are shown at microscopic magnification in Fig.13. The plain weave 1/1 fabric was selected as the reference sample for comparison of reproduction quality. Differences in reproduction quality are more pronounced in Sample 3, where the fabric structure and greater surface heterogeneity become visually dominant, affecting the clarity of details and the overall appearance of the reproduced photograph.
Microscopic images of the selected blue-and-white segment of the photograph (Fig.13) further demonstrate the influence of fabric structure on the accuracy of the printed motif reproduction.
Differences in the arrangement of interlacing points and yarn floats determine the surface topography of the fabric, resulting in differences in the distribution of process printing inks within individual areas of the motif across the three samples. Consequently, local variations occur in the shape and clarity of the reproduced element, as well as in the uniformity of colour reproduction. These differences are most pronounced on the structurally heterogeneous surface of the mixed panama fabric.
The visual/subjective and microscopic analyses of the photographic print therefore confirm the influence of fabric structure and surface topography on the reproduction of image details, colour appearance, and overall image quality.

4. Conclusions

The complexity and heterogeneity of textile structures affect their surface properties and, consequently, the interaction of printing ink with the textile substrate and the final quality of the digital inkjet print. In this study, spectrophotometric, image, visual, and microscopic analyses were used to investigate the influence of different fabric structures and their associated surface topography on colour reproduction and print quality.



Fig.12 Segments of photograph for visual/subjective analysis

ink spreading and a less regular contour of the printed line. Visual and microscopic analyses of the

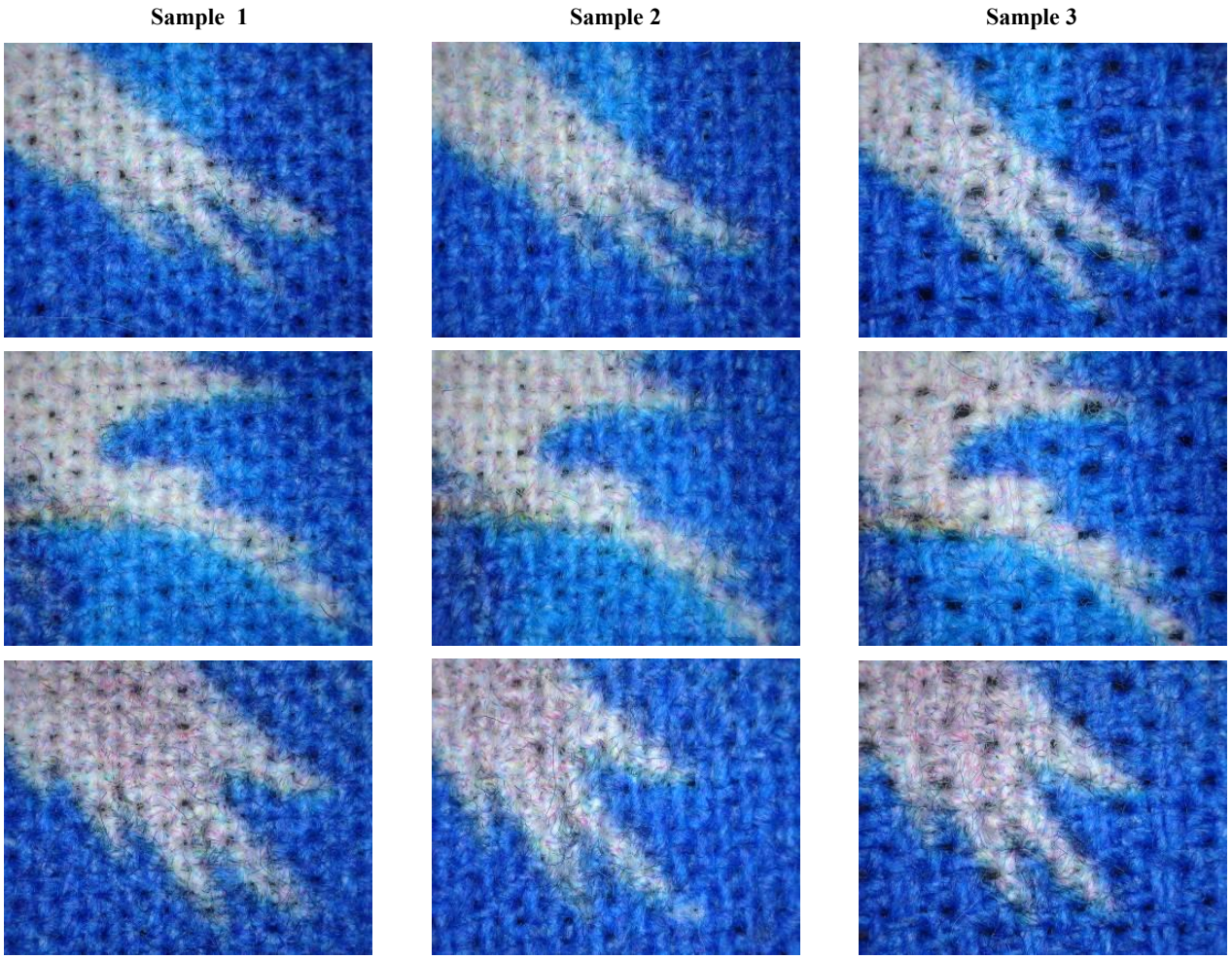


Fig.13 Visual/subjective analysis of the segment on the photograph scanned with the Dino-Lite microscope, magnification 50x

The spectrophotometric results revealed differences in the spectral and colorimetric characteristics of the same colours reproduced on fabrics with different structures. The calculated colour differences for the twill 2/1 and mixed panama 2/1 samples relative to the reference plain weave 1/1 sample exceeded the previously defined threshold of $\Delta E < 2$, confirming the influence of fabric structure and surface topography on colour reproduction. Image analysis further demonstrated the influence of fabric structure on the geometric accuracy of the reproduced printed element.

The lowest area and perimeter values of the printed line were obtained for the plain weave 1/1 fabric, while the highest values were obtained for the mixed panama 2/1 fabric. The greater number of interlacing points and the more uniform surface structure of the plain weave limit the lateral spreading of the printing ink and enable more regular reproduction of the printed element. In contrast, longer yarn floats and greater surface heterogeneity of the twill and mixed panama fabrics are associated with more pronounced photographic print further confirmed differences in the reproduction of image details among fabrics with different surface structures. Overall, the results demonstrate that the structure and surface topography of the textile substrate play an important role in colour reproduction, the accuracy of graphic element reproduction, and the overall quality of digital inkjet printing.

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