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ORIGINAL ARTICLE

Coloration Technology

Assessment of the UV inkjet ink penetration into laboratory papers within triticale pulp and its influence on print quality

Irena Bates | **Ivana Plazonić** | **Katja Petric Maretić** | **Maja Rudolf** | **Valentina Radić Seleš**

Faculty of Graphic Arts, University of Zagreb, Zagreb, Croatia

Correspondence
Irena Bates, Faculty of Graphic Arts, University of Zagreb, Getaldićeva 2, 10 000 Zagreb, Croatia.
Email: irena.bates@grf.unizg.hr

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Abstract

Today the print quality of digital printing techniques has improved and is considered satisfactory and competitive to analogue techniques for certain graphic products. Satisfactory print quality mostly depends on the interaction of ink and printing substrate where ink penetration has an important role. Namely, the ink penetration affects the parameters that describe the print quality together with visual appearance of print density and mottling. Therefore, it is important to select an adequate printing substrate for each printing technique. Awareness of environmental problems related to the shortage of wood raw materials has led to an increase in the use of recycled printing paper and in particular the implementation of new alternative sources of cellulose fibres instead of virgin wood fibres in the papermaking process. In this research the emphasis is precisely on defining the influence of ink penetration into laboratory papers made of triticale pulp on the final print quality. The laboratory printing papers were obtained by mixing triticale pulp with pulp from recycled fibres in three different portions. Papers were thereafter printed by ultraviolet (UV) inkjet printer and the ink penetration within laboratory papers with and without straw pulp was analysed using two methods of ink penetration analysis (microscopic/spectroscopic). The influence of ink penetration on the final print quality was observed and analysed based on several quality parameters (optical ink density, mottling and colorimetric values). These results confirmed that triticale pulp in laboratory papers provides equal print quality compared to laboratory papers made only from pulp from recycled fibres.

1 | INTRODUCTION

The packaging and labels graphic industry is dominated by several main printing techniques, namely flexography, offset, gravure and digital printing. Each technique is suitable for a particular type of graphic product and differs in the way ink is transferred to the printing substrate and by the type of image carrier employed. Depending upon the printing process, the printing ink is transferred to the substrate either directly or indirectly. High-quality prints in analogue technologies are based on ink transfer from printing plate to printing substrate, while digital printing is based on inkjet or statical ink transfer directly to the printing substrate. Since the development of digital commercial printing in the mid-1990s, devices have emerged that can reproduce almost the same quality in any required application. Digital printing has created a revolution in the printing industry, where inkjet printing and electrophotography printing are fast-growing digital printing techniques. Inkjet printing is one of the most popular non-impact printing technologies, where printing is performed without pressure and printing plates. During the printing process, the ink is applied directly to the printing substrate from a jet device driven by an electronic signal.[1,2] Due to its ability to provide the required quality of prints on a wide variety of substrates, the digital printing process is a complementary technology to analogue technologies used for short runs in the printing of labels, packaging, and publications.[3] In order to achieve high-quality print, it is necessary to be aware of the characteristics of the substrate and the possibilities of each printing technique. The main focus of this research is to examine the effect of ink penetration into laboratory papers with triticale pulp on overall print quality. Wood is still the basic raw material for paper production, and its demand is increasing daily causing deforestation, environmental imbalances and global warming. Therefore, new sources of raw materials for pulp and paper production are necessary. The current world consumption of pulp based on the proportion of raw materials is, respectively, wood pulp with 63%, used paper pulp 34%, and non-wood pulp 3%. The limited availability of wood raw materials has forced the pulp and paper industry to use recyclable paper and/or to introduce other sources of cellulose fibres, such as non-wood raw materials, into paper production. Wood fibres cannot be recycled indefinitely, after 5–7 cycles of the recycling process fibres are no longer usable as they are too short and they crumble.[4] For these reasons recycled fibres cannot provide the same level of paper quality products as virgin fibres can, therefore the pulp of recycled fibres during paper manufacturing needs to be enriched with virgin cellulose fibres. It would be desirable if the virgin cellulose fibres used for this purpose would come from an alternative non-wood origin. The alternative fibres are roughly divided into four categories: purposely cultivated crops, agricultural residues, industrial residues, and uncultivated crops occurring in nature.[5] Non-wood raw material is a valuable resource of cellulose fibres in regions where forest resources are limited and where there is a high production of certain cultivated crops.[6] Recently, agricultural residues have become one of the most significant alternative resources for fibre isolation as they are economical, abundant and renewable.[7,8] The current usage of non-wood fibre sources in papermaking include straw, sugar cane bagasse, bamboo, kenaf, hemp, sisal, abaca, cotton linter and reeds, as well as some exotic raw materials like aquatic plants, tea waste, palm leaf and banana stem.[9]

In this research, laboratory printing papers were produced on a laboratory sheet former using a mixture of triticale pulp in different weight ratios (10%, 20% and 30%) and pulp of recycled fibres. Adding triticale pulp to recycled fibres pulp to create an innovative paper is of great importance considering that straw is currently burned or rots on the ground.[10] To achieve optimal quality reproduction of graphic products it is necessary to be aware of paper substrate characteristics and its possibilities for printing with certain printing techniques.[11]

Namely, after transferring ink onto the printing substrate, the ink spreads directly along the substrate fibres and penetrates in the bulk of the substrate.[12] The ink penetration into the printing substrate depends on the physical and chemical properties of the printing substrate and the inks used. The final print quality also depends on the interaction between the ink and the printing substrate. If the ink droplets spread on the surface faster than they penetrate, they could cause dot gain[13] and extend the drying time of the printed material. Penetration of ink can be defined as surface dispersion on the cellulose fibres or diffusion through the cellulose fibres in paper composition. If the ink penetrates deep into the substrate fibres, the ink could penetrate through the paper and the optical density of the print would be poor. Therefore, it is important to analyse the movement of ink within the porous structure of the printing substrate produced with cellulose fibres from non-wood raw materials. In the first phase of this research, the printability or utilisation of printing substrates with triticale pulp was formed at the laboratory level. It is important to emphasise that laboratory made printing substrates have a very open surface as they do not undergo calendaring or other final stages of the paper production process, which can lead to deep ink penetration into the paper structure.[14] Paper is considered as a heterogeneous printing substrate because of its composition where cellulose fibres make a network in which several additives are present in higher or smaller quantities. Laboratory-formed paper sheets have an even more inhomogeneous structure than industrial-made papers.[15]

2 | EXPERIMENTAL

2.1 | Laboratory papers

Triticale (*Triticale* sp.) is a hybrid crop of wheat and rye and is a relatively new grain culture, which is increasingly used in agricultural production. Straw obtained from the winter variety of triticale was collected after the harvest, manually cut into 3 cm long pieces and conducted into semi-chemical

TABLE 1 Pulping conditions

Non-wood plant material	Pulping method	Pulping conditions
Triticale straw	Soda pulping	Temperature of 120°C, alkali level of 16% for 60 minutes and 10:1 liquid to biomass

pulp using the soda pulping method. Pulping conditions are presented in Table 1.[9]

Laboratory papers of approximately 42.5 g/m^2 (20 cm diameter) were formed in a Rapid-Köthen sheet former (FRANK-PTI) according to EN ISO 5269-2:2004 nine standards from a mixture of triticale pulp (in proportions of 10%, 20% or 30%) and pulp from recycled wood fibres (Figure 1). Figure 1 presents the process flow of laboratory paper production.[11]

Laboratory paper substrates formed from recycled wood pulp (100%) were used as control samples (N) to compare the quality of papers with the addition of triticale pulp. In total, according to their composition, three different laboratory papers with triticale pulp (1NT, 2NT, 3NT) were formed. Their composition and some basic characteristics are presented[11] in Table 2.

Figure 2 presents SEM (scanning electron microscopy) images of the control paper substrate (Figure 2A), paper substrates made only from triticale fibres (T) (Figure 2B) and paper substrates made from a mixture of triticale fibres and recycled wood fibres (3NT) (Figure 2C). SEM images were obtained using a JEOL scanning electron microscope with field emission (JSM-7800F) with a maximum resolution of 0.8 nm, acceleration voltage between 0.01 and 30 kV and magnification range: ×25-1 000 000. From the SEM images magnified ×1000, it is obvious that the surface of laboratory paper substrates made only from recycled fibres pulp (Figure 2A) and in a portion of 70% (Figure 2C) are rougher, but also more heterogeneous than those made only from virgin triticale fibres (Figure 2B).

2.2 | Printing of laboratory papers

To analyse ink permeability into laboratory papers containing triticale pulp and their printability, the samples were printed by a digital EFI Rastek H652 UV curable inkjet printer. This printer uses two dual-intensity ultraviolet (UV) lamps (with the power rating of 700 W) that cure UV ink by the shortest curing times and exceptional polymerisation. The drying process involves UV radiation for the crosslinking of organic molecules (monomers), that is radiation curing. The used ink and its interaction with the substrate determine the thickness of the ink layer on the substrate and thus the overall print quality. The thickness of the UV ink layer on the printing substrate ranges between 10 and 15 μm, where the dynamic viscosity of the ink is the most common between 1 and 30 mPa·s.

In non-impact technologies, such as inkjet, the print quality depends on the resolution of imaging systems (dots per

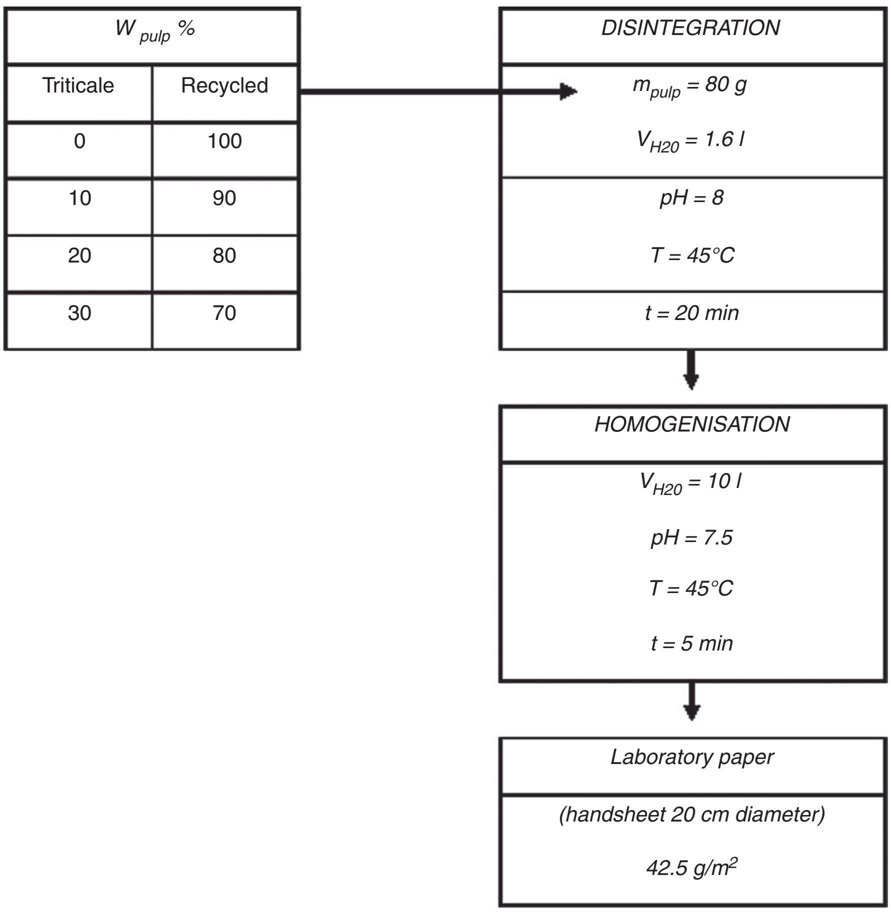

FIGURE 1 The process flow of laboratory paper production

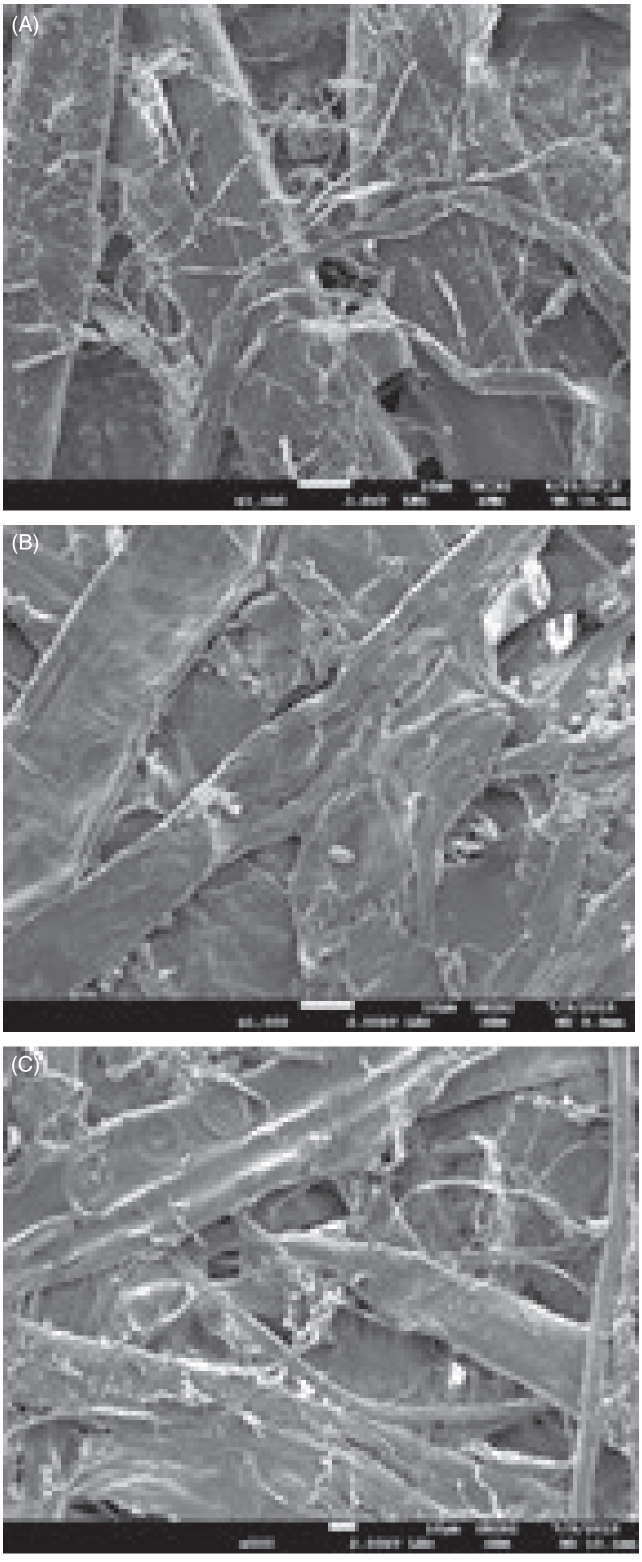

FIGURE 2 SEM images (magnification ×1000) of laboratory papers of different composition: (A) N; (B) T; (C) 3NT

inch [dpi]), the quality of the shape of the individual image element (pixels), the ability to transfer different amounts of ink per image element (variation of ink film thickness) and the screening.[1] Variable drop-on-demand piezoelectric printing technique ensures full tone areas of cyan, magenta and yellow inks to be printed at a resolution of 600 × 600 dpi (respectively, with high-quality mode eight pass), at printing speed of 12.10 m^2/h on laboratory paper formed only from recycled wood pulp and on each laboratory paper with the addition of triticale pulp. In this technique, the printing process is performed based on ink droplets sprayed from the printhead nozzles and the data of the digital print job is transferred directly to the inkjet system, which transfers the ink to the printing substrate via the nozzles.

To measure the trapping parameters, the samples were additionally printed by single-pass systems with two inks one above the other in full tone cyan and yellow, magenta and yellow, cyan and magenta, and with three inks one above the other with cyan, magenta and yellow. The inks were printed separately on top of each other after the drying process to define the acceptance of the ink on the previously printed ink or inks. Reproduction of the full tone areas is directly controlled by a raster image processor based on a print job described entirely in digital form.[16] Multicolour printing based on non-impact technologies can be performed either based on multipass or single-pass systems. Single-pass systems contain a separate ink transfer from the print head onto the printing substrate for each colour.[1]

2.3 | Analysis

The assessment of the influence of ink penetration into laboratory papers with triticale pulp on the print quality was divided into two parts.

The first part, the analysis of ink penetration on printed laboratory papers was observed using two methods. The first method, ink penetration depth analysis, was made using the microscopic method (processing a microscopic image taken on prepared cross-sectional samples of each print), and the second method calculated ink penetration depth using the Kubelka–Munk theory (spectroscopic method) from reflectance measurements (R_∞, R_0, R_p, R_q).[17,18]

The second part, the analysis of print quality or printability, was focused on mottling (print unevenness), optical ink density, colorimetric values and trapping values measured on prints made on laboratory papers with and without triticale pulp.

2.3.1 | The analysis of ink penetration on printed laboratory papers

Microscopic method

Cross-sectional samples were prepared from 10 mm × 30 mm strips cut by the Leica RM 2255 rotary microtome device and embedded in epoxy resin. The epoxy resin used is a mixture

TABLE 2 Laboratory papers composition and some basic characteristics

Laboratory papers	Composition, W (triticale pulp:recycled pulp) (%)	Thickness (µm) ISO 534 (2011)	Ash (%) ISO 2144 (2015)	Water absorption, M5min (%) ISO 5637 (1989)	Roughness, Ra (µm) ISO 4287–1 (1997)
N	0:100	94.0 ± 2.79	4.73 ± 0.22	171.23	4.15 ± 0.34
1NT	10:90	96.3 ± 6.35	4.19 ± 0.47	252.86	4.25 ± 0.56
2NT	20:80	98.3 ± 6.68	3.89 ± 0.15	263.26	4.37 ± 0.34
3NT	30:70	99.4 ± 6.20	3.39 ± 0.15	264.48	4.40 ± 0.39

of Epofix resin (containing bisphenol-A-diglycidylether) and Epofix hardener (containing triethylenetetramine) mixed in volume ratio 15:2. The samples were cold-sealed and dried at room temperature over a period of 12 hours, without pressure prior to grinding and polishing which were performed using a Buehler grinder machine and Struers DAP-V polishing machine. The cross-sectional images of the samples were recorded using an Olympus GX 51 light microscope with the AnalySIS program at a magnification of ×200 and further analyzed with the IMAGEJ program.

The maximum ink penetration depth (Hp_m) was calculated from the 50 sections obtained from the microscopic images (Equation 1).

$$Hp_m = \frac{l}{d} \times 100 \quad (1)$$

where l is the maximum ink penetration value and d is the local thickness of paper in the measuring section.

Spectroscopic method

Using the non-destructive method, ink penetration depth (Hp_s) was determined by surface analysis using reflectance values based on the Kubelka–Munk theory (Equation 2).[19-21] The ink penetration depth was determined from the average reflectance value of 50 spectrophotometric measurements.

$$Hp_s = \frac{\ln \frac{(1-R_0 \times R_\infty)(1-R_p \times R_\infty)(1-R_q/R_\infty)}{(1-R_0 \times R_\infty)(1-R_p/R_\infty)(1-R_q \times R_\infty)}}{\ln \frac{1-R_0 \times R_\infty}{1-R_0/R_\infty}} \quad (2)$$

where R_∞ is the reflectance value of unprinted laboratory paper over the opaque pad of unprinted laboratory papers, R_0 is the reflectance value of unprinted laboratory paper over a standard black background, R_p is the reflectance value of printed laboratory paper over opaque pad of unprinted laboratory papers, R_q is the reflectance value of the reverse side of printed laboratory paper placed over opaque pad of unprinted laboratory papers and D is an average value of unprinted laboratory paper thickness.

The required reflectance values (R) were measured by a spectrophotometer eXact, X-Rite with a measurement geometry of 45°/0° (D65/10°) at 457 nm (brightness) according to the Tappi T452 standard.

2.3.2 | The analysis of print quality or printability

Mottling

The assessment of print unevenness or mottling was performed by a digital microscope PIAS-II using software compliant with the ISO-13660 print quality standards. The mottling parameter was defined on a large-scale (> 1270 µm) where the observed area was divided into 100 uniform tiles (1.27 mm × 1.27 mm). The mean value (m_i) of 900 reflectance measurements was calculated in each tile. Mottling is defined as the standard deviation of the mean reflectance values of the tiles according to Equation 3.

$$\text{Mottle} = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} \left(m_i - \left(\frac{1}{n} \sum_{i=1}^{n} m_i\right)\right)^2} \quad (3)$$

where m_i is the mean value of the reflection coefficient and n is the total number of tiles, 15.

Optical ink density

The optical ink density (D_i) was determined on full tones of cyan and magenta by a densitometer Exact, X-Rite (D50/2°) to measure the value of ink film thickness on laboratory papers. The optical ink density was calculated according to Equation 4.

$$D_i = \log \frac{I_0}{I} \quad (4)$$

where I is the light intensity of the light reemitted by the ink film in relation to the intensity of light, I_0 reemitted by unprinted laboratory paper. The average optical ink density of each of the full tones was obtained from 50 measurements.

Colorimetric values

The optical properties of the printed laboratory papers were monitored with a SpectroEye, X-Rite spectrophotometer at D50/2°, and observed through colorimetric values: L*

(lightness), a^* (coordinate of green/red colour) and b^* (coordinate of blue/yellow colour). The average colorimetric value of each of the full tone areas was determined from 50 measurements.

The Euclidean colour difference (ΔE_{00}^*) was additionally used for improved measurement of differences in colour between observed printed laboratory papers. The value of ΔE_{00}^* was calculated according to Equation 5, using printed laboratory paper without triticale pulp (N) as a reference and printed laboratory papers with triticale pulp (1NT, 2NT, 3NT).

The total amount of ink on the paper surface was monitored based on the Euclidean difference according to Equation 5 between the undertone of printed laboratory paper and the undertone of unprinted laboratory paper, where the change in colour of the back of the printed laboratory paper should not be greater than the visible visual perception.

Average colorimetric values and standard deviation of 50 measurements are used in Equation 5, where lightness difference (ΔL') was calculated between the undertone of unprinted laboratory paper and the undertone of printed laboratory paper. The chroma difference (ΔC') was calculated between the undertone of unprinted laboratory paper and the undertone of printed laboratory paper, while ΔH' was calculated between the undertone of unprinted laboratory paper and the undertone of printed laboratory paper.

$$\Delta E_{00} * = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_L S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)} \quad (5)$$

where $\Delta L'$ is the lightness difference between prints on papers without and with triticale pulp, $\Delta C'$ is the chroma difference between prints on papers without and with triticale pulp, $\Delta H'$ is the hue difference between prints on papers without and with triticale pulp, R_T is the rotation function, K_L, K_C, K_H are the parametric factors for variation in the experimental conditions and S_L, S_C, S_H are the weighting functions. According to tolerance definition, $\Delta E_{00}^* \leq 2$ is classified as a very small noticeable difference for the standard observer, while $\Delta E_{00}^* = 5$ is defined as a big noticeable difference in colour that a standard observer can recognise.[22,23]

Total amounts of ink on printed laboratory papers

Total amounts of ink on printing laboratory papers were observed based on the colorimetric difference between the undertones (back of the print) of the printed laboratory papers and the back of the unprinted laboratory papers. The spectrophotometric values of the undertone values of unprinted and printed laboratory papers were determined with a SpectroEye spectrophotometer (under the conditions: standard illumination D50, status *E* and viewing angle 20).

Trapping values

One of the main parameters that affect the print quality is the satisfactory acceptance of ink to the previously printed ink. In order to obtain multicolour prints in the graphic industry, they are produced based on the subjective principle of colour mixing, where different tonalities of printing are achieved by printing solid areas and/or halftones of ink one on top of each other. The Preucil method is a commonly used method based on densitometric measurements for determining the ink trap on the previously applied ink. Trapping values (AT) are measured on full tone areas where two or three inks are printed one above the other (cyan + yellow, magenta + yellow, cyan + magenta and cyan + magenta + yellow) and are calculated according to Equation 6.

$$\text{AT} = \frac{D_{op} - D_1}{D_2} \times 100 \quad (6)$$

TABLE 3 Characteristics of the control sample (N) – Ink penetration depth (Hp_m and Hp_s) and print quality parameters (mottling and optical ink density)

Characteristics		Printed ink	Values
Ink penetration depth	Measured by microscopic method (Hp_m), µm	Cyan	63.40
		Magenta	82.87
		Yellow	81.66
	Measured by spectroscopic method (Hp_s), %	Cyan	44.15
		Magenta	35.43
		Yellow	41.56
Print quality parameter	Mottling (m)	Cyan	0.10
		Magenta	0.08
		Yellow	0.05
	Optical ink density (*Di*)	Cyan	1.09
		Magenta	0.95
		Yellow	0.91

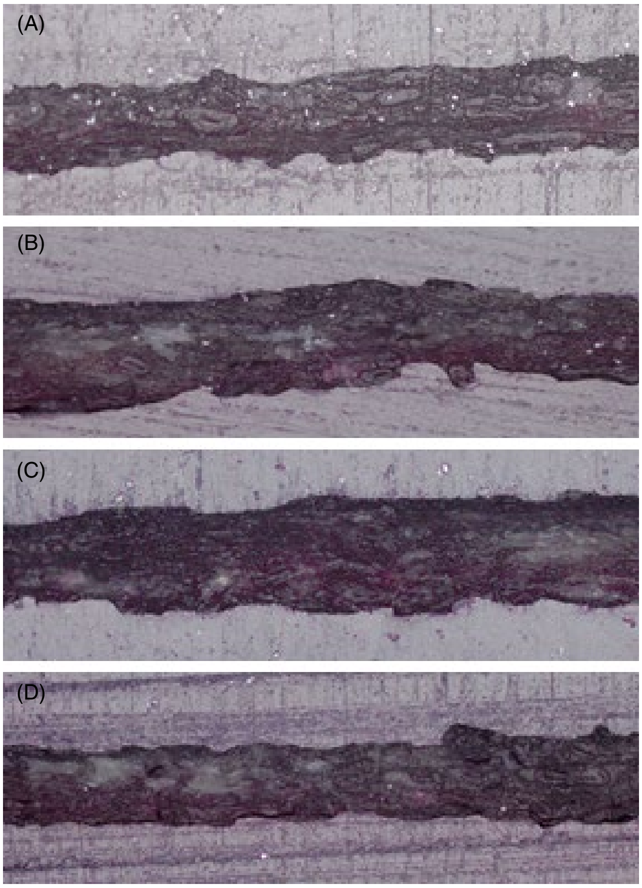

FIGURE 3 Microscopic images of magenta ink penetration into laboratory papers: (A) N; (B) 1NT; (C) 2NT; (D) 3NT

where D_1 is the ink density of the previously printed ink/two inks; D_2 is the ink density of the last printed ink and D_{op} is the ink density of overprint. Whereby, the densities of the ink (D_i) are observed by using a colour filter of the last printed ink. The average values of all mentioned optical ink densities were obtained from 50 measurements.

It is desirable that the value of trapping is high, which means better acceptance of the last printed ink on the previous printed ink or inks.

Table 3 summarises values of cyan, magenta and yellow ink penetration depth determined by spectroscopic and microscopic methods and print quality parameters (mottling and optical ink density) for the control sample (N).[24] These results are used to compare the results obtained on papers with triticale pulp in order to expand the knowledge about the possibility of utilising triticale straw in the production of paper products intended for printing.

3 | RESULTS AND DISCUSSION

3.1 | Measurement of ink penetration depth

Since the penetration of ink into the paper substrate is a complex issue, there are several approaches to determining the depth of ink penetration. The most common and complementary method is the combination of microscopic and spectroscopic methods as they provide the best insight into the actual distribution of ink in substrates and its influence on the final print quality.[14]

The microscopic method is not reliable enough alone due to some factors that affect the accuracy of the results, such as resin penetration and the small size of the observed sample. Figure 3 shows microscopic images of cross-sections of magenta prints into laboratory papers without (N) and with triticale pulp (1NT, 2NT, 3NT).

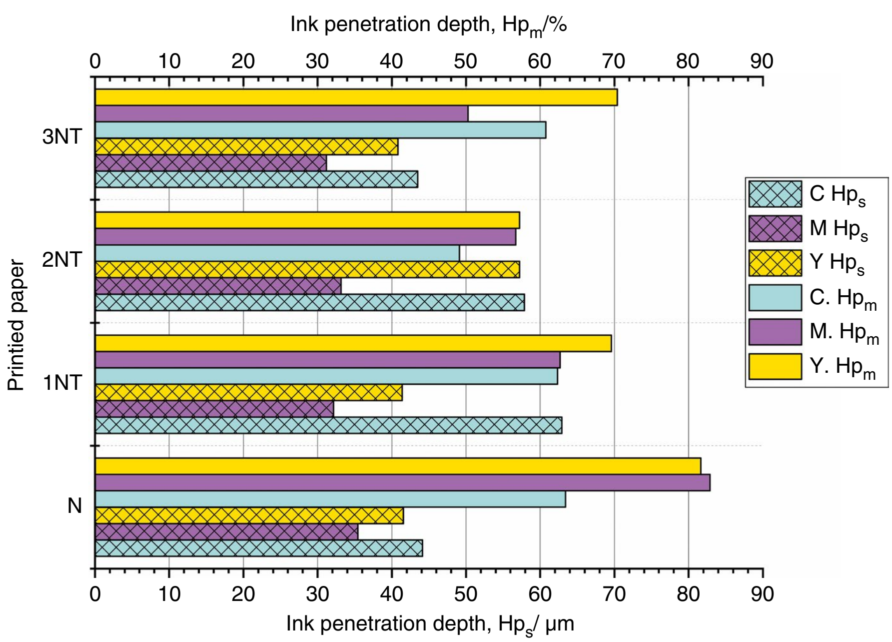

FIGURE 4 Maximum ink penetration depth determined by microscopic and spectroscopic methods

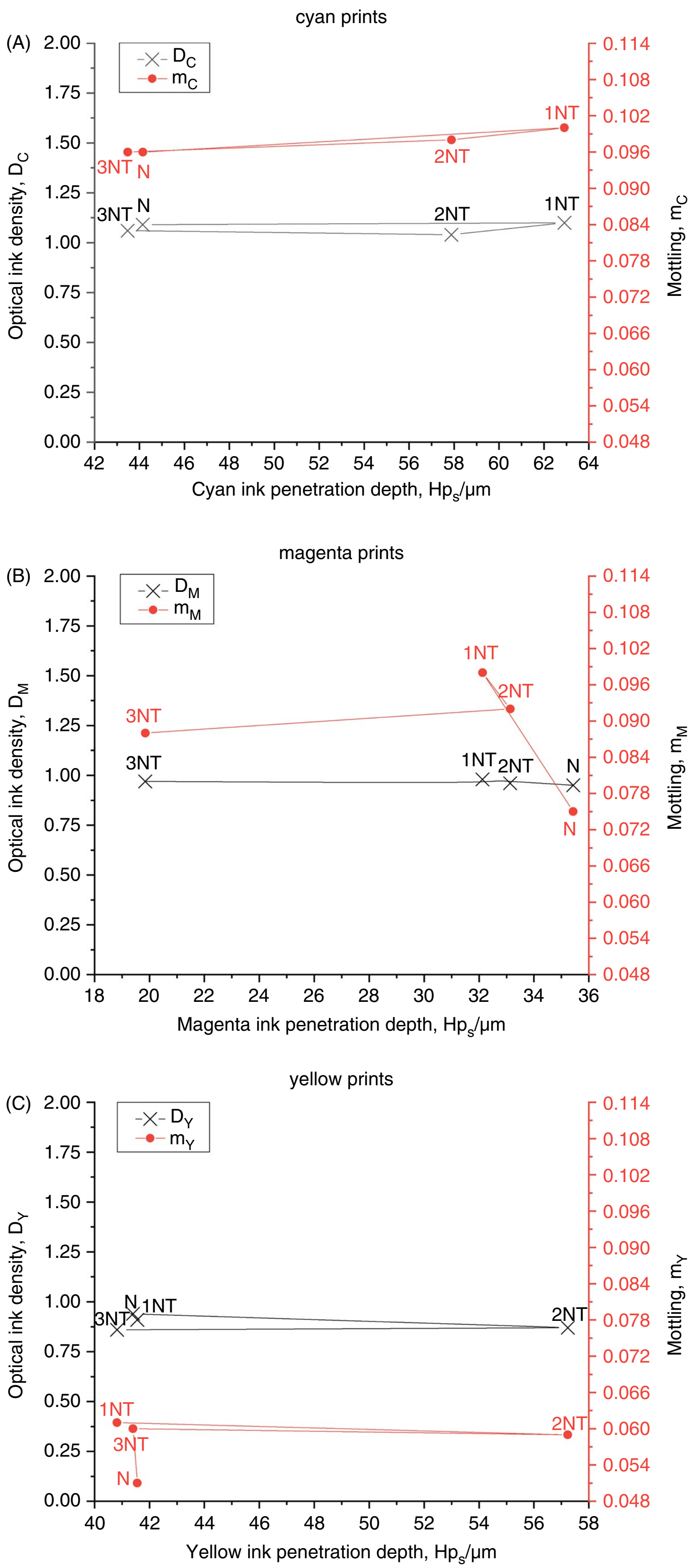

FIGURE 5 The values of mottling (unevenness of solid areas) and optical ink density with respect to ink penetration depth determined by spectroscopic methods on prints: (A) cyan; (B) magenta; (C) yellow

TABLE 4 The Euclidean colour difference (ΔE_{00}*) between printed reference laboratory paper without triticale pulp (N) and printed laboratory papers with triticale pulp (1NT, 2NT, 3NT)

	Printed ink		
ΔE_{00}	Cyan	Magenta	Yellow
N vs 1NT	2.51	2.20	1.50
N vs 2NT	4.33	2.15	2.12
N vs 3NT	5.75	2.60	2.80

The microscopic images shown in Figure 4 are cross-sections of the magenta prints having the high ink penetration depth obtained by the microscopic method (Hp_m), while results obtained by the spectroscopic method (Hp_s) have the lowest ink penetration of these prints.

All printed laboratory papers showed greater ink penetration depth measured by the microscopic method than by using the spectrophotometric method. The results obtained by spectrophotometric measurements indicate very similar values of ink penetration within laboratory papers, regardless of whether it is formed with or without straw pulp.

The highest values of ink penetration depth ($Hp_{m(N)}$ = 82.87%) were observed on the magenta control sample (N) measured by the microscopic method.

The prints obtained on 1NT and 2NT laboratory papers show ink penetration depth results that partially coincide in both microscopic and spectroscopic methods.

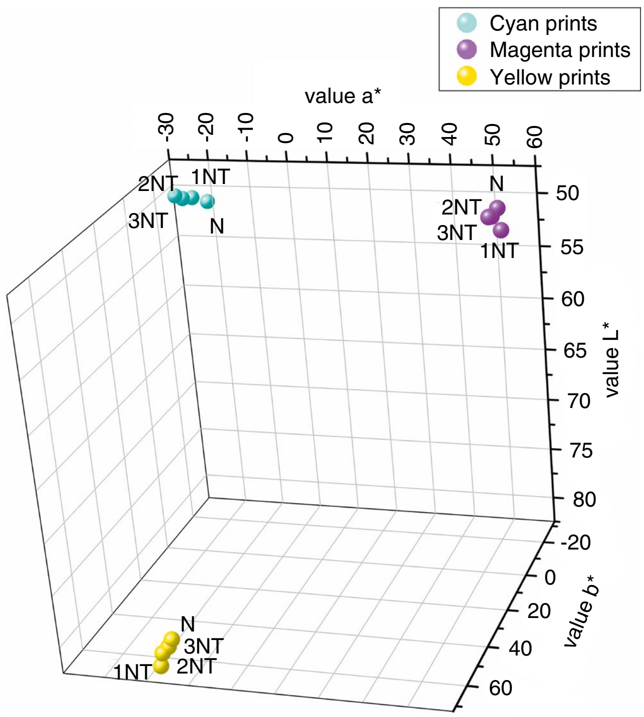

FIGURE 6 Colorimetric values of prints in the CIE $L^*a^*b^*$ colour space

Magenta prints contain the lowest average values of ink penetration depth determined by the spectroscopic method ($Hp_{s(3NT)}$ = 31.20%), while cyan prints on all observed laboratory papers have very similar results of ink penetration depth in both methods.

These results indicate that cyan, yellow and magenta inks do not have uniform distribution within the same laboratory paper.

According to spectroscopic and microscopic methods, the addition of triticale pulp to laboratory papers gives a similar or slight decrease in the value of ink penetration depth on all observed prints.

Since the results determined by the spectrophotometric method are not affected by external factors and since other studies have confirmed a good correlation with the measured data in inkjet printing,[25] this method will be used in further comparisons.

3.2 | Assessment of print quality

The influence of ink penetration into laboratory papers with triticale pulp on the final print quality was observed based on several main parameters. Mottling, optical ink density and colorimetric values were used to assess print quality on each laboratory paper with triticale pulp.

Figure 5 presents the relationship between the results of qualitative parameters (mottling and optical ink density) and ink penetration depth obtained by spectrophotometric measurements.

A similar optical ink density was achieved on all laboratory papers without and with triticale pulp printed with UV inkjet inks. Adding straw pulp into laboratory papers slightly increased the mottling values of magenta ($\Delta m_{(N\text{-}1NT)} = 0.023$) and yellow prints ($\Delta m_{(N\text{-}3NT)} = 0.010$), while on cyan prints this influence was insignificant.

Cyan ink as the most penetrating ink contains almost equal values of mottling and optical ink density on all observed prints.

Figure 6 shows that the achieved colorimetric values of the prints on laboratory papers with the addition of triticale pulp ($L^*a^*b^*$) are almost equal to the prints obtained from the recycled wood pulp (N).

Results in Table 4 show that all prints on laboratory papers with triticale pulp compared to reference print samples (N) show a small colour difference, except for prints with cyan ink on laboratory papers with 20% and 30% triticale pulp where the colour difference is noticeable to the standard observer. Cyan prints compared to other prints on the same laboratory paper have higher values of the Euclidean colour difference. Observing the laboratory papers, it is clearly visible that the highest values of the Euclidean colour difference are achieved on printed laboratory papers with 30% triticale pulp.

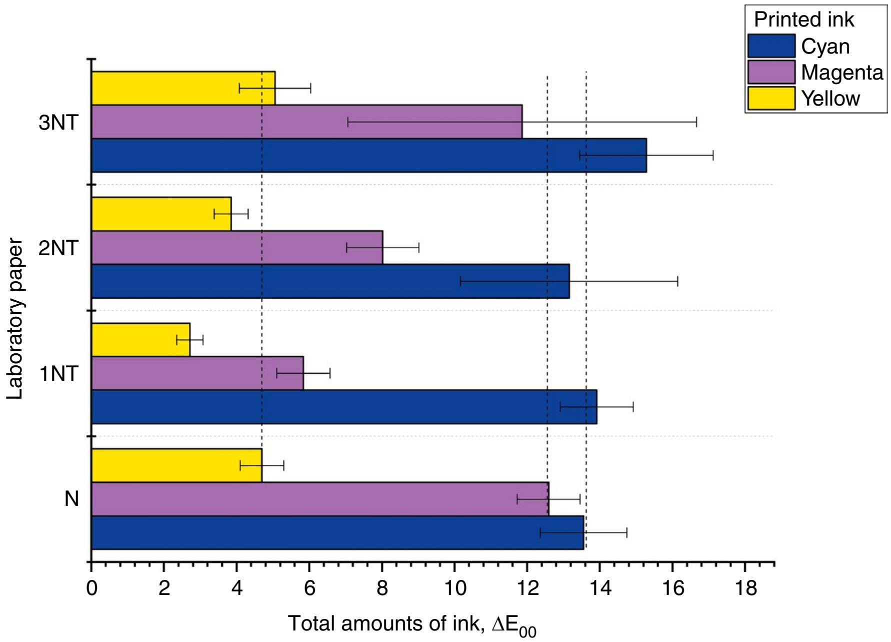

FIGURE 7 Total amounts of ink on printed laboratory paper (N, 1NT, 2NT, 3NT) printed with cyan, magenta and yellow ink

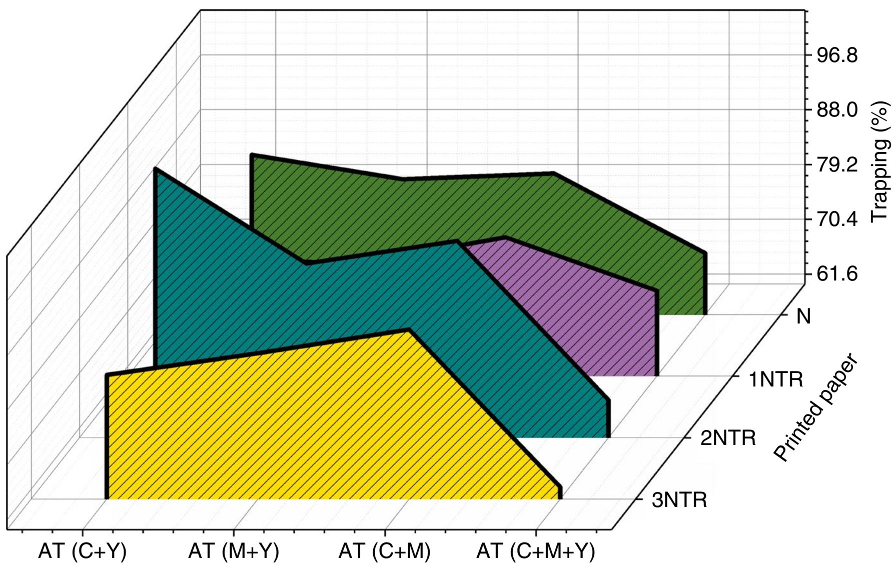

FIGURE 8 Trapping values of printed laboratory papers

Total amounts of ink on all analysed printing laboratory papers are presented in Figure 7. The results show that only printed laboratory papers with 30% triticale pulp with cyan ink have significantly greater colorimetric differences between the undertones (back of the print) of printed laboratory papers and the back of unprinted laboratory papers than printed reference paper made without triticale pulp (N).

In order to define a required print quality and the utility of laboratory sheets with the addition of triticale pulp, trapping values were additionally observed. The main parameter that affects the print quality in multicolour printing is the satisfactory ink acceptance of the previously printed ink, respectively, the great trapping values.

Figure 8 shows that prints with cyan + yellow ink on the control sample (N) have the highest trapping value of 85.72%, while the lowest trapping value was measured on prints with cyan + magenta + yellow ink ($AT_{C+M+Y+m+y}$ = 69.90%). The highest trapping values were achieved by printing cyan and yellow ink on laboratory papers with the addition of 20% triticale pulp (AT_{C+Y} = 88.00%). When printing with three inks (one printed over the other, cyan + magenta + yellow), a decrease in the trapping values was observed in all prints, and the lowest value was measured in prints on laboratory papers with 30% of triticale pulp.

The results of trapping values on all prints enable us to determine that equal or even higher reproduction quality was achieved on laboratory papers with triticale pulp compared to the control sample (N).

4 | CONCLUSION

The print quality of UV inkjet prints depends on the printing technology, ink properties and paper characteristics. From the measured data assessing the ink penetration into laboratory papers with triticale pulp and its influence on print quality, the following conclusions can be drawn:

1. the microscopic method has proved as a good method for visual insight into paper–ink interaction, while the spectroscopic method provides more objective results of ink penetration depth;
2. the differences between the maximum and average ink penetration depths are reduced by adding triticale pulp into laboratory paper, which may indicate the uniform distribution of ink into paper substrates;
3. samples printed with cyan inks achieve the required print quality, while only noticeable degradation of print unevenness is measured on laboratory papers with triticale pulp printed in yellow and magenta regardless of the portion of triticale pulp in laboratory papers;
4. based on all observed print quality parameters (mottling, ink optical density, colorimetric values and Euclidean colour differences) it has been proven that the addition of triticale pulp in laboratory papers provides equal print quality compared to laboratory papers made only from recycled pulp;
5. the correlation between the greater depth of ink penetration measured by the microscopic method and large increased value of total amount of ink on laboratory paper and Euclidean colour differences on printed laboratory papers with 30% triticale pulp is the result of higher paper absorption, roughness and lower share of fillers in the laboratory papers with a higher share of triticale pulp;
6. based on similar trapping results, it can be concluded that very small differences in ink distribution within laboratory papers with triticale pulp do not affect ink acceptance on previously printed ink.
7. assessment of ink penetration into laboratory papers and analysis of printability confirm that paper with the addition of triticale pulp can be used in the printing industry to reduce the exploitation of wood fibre resources.

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ORCID

Irena Bates https://orcid.org/0000-0002-3133-229X
Ivana Plazonić https://orcid.org/0000-0002-9721-6750
Katja Petric Maretić https://orcid.org/0000-0001-9818-4511
Maja Rudolf https://orcid.org/0000-0002-3959-952X
Valentina Radić Seleš https://orcid.org/0000-0003-4988-0697

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