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EVALUATION OF THE LINE AND EDGE QUALITY OF PRINTED LETTERS ON RECYCLED PAPER WITH STRAW PULP

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Abstract: *Traditional papermaking is based on the use of an aqueous suspension consisting of cellulose fibres obtained by processing wood, non-wood plants or waste paper. With growing environmental concerns regarding deforestation and CO_2 production, the paper industry has been always looking for new sources of non-wood pulp that would produce papers of similar quality to those made from wood pulp. Cereal straw from wheat, barley or triticale crops that remains on fields as a residue after grain harvesting has proven to be a good substitute for virgin wood fibres needed in the production of recycled paper. In this study, the quality of printed text on recycled paper with added straw pulp is evaluated mainly based on the line and edge characteristics of the printed letters. For this purpose, three types of laboratory paper substrates were first prepared using recycled wood pulp with the addition of 30% wheat, barley, or triticale straw pulp. The same letter pattern was printed with black ink on each paper substrate at a standard size of 12 pt with two common typefaces: Arial and Times New Roman. The quality of the printed letters was assessed through the measured print quality parameters such as blurriness, raggedness, fill and contrast. The resulting measurements were compared with the results obtained on the reference and control samples made exclusively from recycled wood pulp as a substrate from laboratory and commercial production. In terms of fill and contrast values, the uniformity of lines printed on the recycled papers with added straw pulp is the same or very similar to the reference and control papers. Letters printed in Arial (sans-serif) typeface show slightly better reproduction quality than letters printed in Times New Roman (serif) typeface. The measured parameters blurriness and raggedness of all laboratory-made paper substrates (with and without straw pulp) had similar values between 0.17 mm and 0.20 mm, resulting in a very similar reproduction quality compared to the reference paper substrate.*

Key words: digital printing, line and edge quality, paper substrate, printed letters, straw pulp

1. INTRODUCTION

The use of papers with alternative sources of cellulose pulp has been widely explored in the recent past, using non-wood, sustainable and renewable materials derived from different types of plants (El-Sayed, El-Sakhawy & El-Sakhawy, 2020). Cereal straw is particularly interesting for paper production because it has a similar cellulose content to wood, and a lower lignin content (Plazonić et al., 2021). It is, also, a cheap and renewable resource compatible with the high demand for paper as packaging and printing medium. Extensive research has been conducted on residual straw of wheat, barley and triticale collected after the crop harvest, and it has shown that cereal straw is a valuable raw material for the paper industry (Plazonić, Barbarić-Mikočević & Antonović, 2016; Plazonić, Barbarić-Mikočević & Džimbeg-Malčić 2014a; Plazonić, Barbarić-Mikočević & Džimbeg-Malčić 2014b).

Papers with an addition of cereal pulp are mostly used for secondary packaging (Kurek et al, 2022) which often contain some kind of printed content: text, barcodes, logos and other types of graphics. This research focuses on evaluating the quality of ink-jet printed text patterns for two different typefaces. Ink-jet printing is one of the most commonly used printing techniques for packaging and labelling in small runs, along with offset and flexography printing. It is a non-contact printing process that does not require ink carrier nor pressure as the ink is applied directly to the printing substrate. However, ink-jet printing can be slower than other conventional printing techniques (Kiphan, 2001). It is particularly advantageous for printing smaller batches, variable data printing and personalized on-demand printing (Li et al., 2018).

For the purposes of secondary packaging, it is very important that the printing medium successfully communicates the printed information because it should, not only serve as protection for the product, but also convey messages in a clear way to ensure good legibility.

The type of substrate has a significant impact on the quality of the printed text (Možina et al., 2020) suggesting that a higher contrast between text and paper and larger text size can contribute to good legibility. Research has also shown that the optimal size for body text is between 8 pt and 12 pt (Možina, 2003). The same parameters used in assessing the quality of line reproduction, such as barcode lines (Bates, Plazonić & Koren, 2014; Korzeniowski, Praiss & Żmich, 2018; Markotić, Puceković & Bates, 2012) can be used to evaluate the quality of printed text (Valdec et al., 2021), namely: blurriness and raggedness as characteristics of line edges, and fill and contrast as parameters of reproduction quality (Tse, 2007). Research on line edge quality conducted by flexographic printing technique showed that those parameters can be applied for different printing substrates such as coated papers, polypropylene (Bates, Petric Maretić & Zjakić, 2014), or even textile prints (Elesini, Pančur & Možina, 2021). Studies on papers to which triticale straw pulp has been added conclude that the printed lines properties are of similar quality to those printed on papers produced only from recycled wood pulp (Bates et al., 2020).

2. MATERIALS AND METHODS

The first step in this research was the formation of the paper samples that served as printing substrates for the assessment of print quality. Phases included here were as follows:

- preparation of recycled newsprint and collected straw for cellulose pulp suspension
- production of laboratory paper substrates from the obtained pulp.

The collected straw from three cereals was manually cut and converted into a semi-chemical pulp according to the soda method in an autoclave at temperature of 120 °C, 10:1 liquid to biomass ratio and an alkali level of 16% for a period of 60 minutes (Plazonić, Bates & Barbarić-Mikočević, 2016). Cereal pulps were added to the recycled newsprint pulp (N) at a weight ratio of 7:3 (newsprint pulp: cereal straw pulp). Recycled newsprint pulp was obtained from the commercial paper (K), which is made from recycled wood pulp used for printing daily newspapers. In the laboratory paper substrate production phase, four different types of samples were produced using the Rapid Köthen sheet former (FRANK-PTI GmbH, Birkenau, Germany) following the standard ISO 5269-2:2004 for production of laboratory sheets. Table 1. lists the marks and abbreviations for the paper substrate samples produced.

Table 1: Composition and abbreviations of commercial and laboratory paper substrates

Abbreviation	Composition	Method of production
K	100% recycled wood pulp paper	commercially produced
N	100% recycled newsprint pulp	laboratory produced
3NW	70% recycled newsprint pulp and 30% wheat pulp	laboratory produced
3NB	70% recycled newsprint pulp and 30% barley pulp	laboratory produced
3NTR	70% recycled newsprint pulp and 30% triticale pulp	laboratory produced

The paper substrate from 100% recycled newsprint pulp (N) was laboratory produced as a reference sample, while commercially produced paper (K) was used as control sample to compare the quality of prints on laboratory and commercially produced papers.
After producing the laboratory paper substrates, the next phase included digital printing of the letter pattern. The pattern consisted of one uppercase and one lowercase letter “A” in the standard size of 12 pt in two common typefaces – Arial and Times New Roman. It was printed over the paper substrates in black ink using the digital printing technique. Printing was carried out by AGFA, Anapurna M1600 (Agfa Graphics NV, Düsseldorf, Germany), piezoelectric drop-on-demand ink-jet printer using UV curable ink.
Print quality analysis was based on measurements of fill, contrast, blurriness, and raggedness of the line edges according to the standard ISO 13660 using a PIAS-II (Personal Image Analysis System) digital microscope and its associated software. These properties are calculated using reflectance measurements of the printed sample (R_{min}) and the reflectance of the paper as a background (R_{max}). Since the printed line edges are never perfectly sharp compared to the ideal lines created in software, the standard uses a

dynamic thresholding to determine the locations where the lines end. Dynamic thresholding method calculates line edges from the paper reflectance (R_{max}) and the line reflectance (R_{min}) (ISO 13660, 2001). Briggs (1999), Dhopade (2009) and Pedersen (2012) apply and evaluate the image quality according to the parameters described in ISO 13660 and give guidelines for their interpretation.

Fill is defined as the apparent uniformity of darkness within the boundary of the line. A result of 1 indicates the greatest uniformity of darkness. Contrast is the relationship between the darkness of the printed area and its field (printing substrate, i.e. paper), and it is calculated using equation 1:

$$Contrast = (R_f - R_i)/R_f \quad (1)$$

where R_f represents the reflectance value in the paper (field), and R_i represents the reflectance of the printed area.

Blurriness and raggedness are two characteristics that define the quality of a printed line edge. Blurriness represents the transition between the printed area and the paper. An ideal line has no transition from print to paper, but due to the inhomogeneous surface of the paper and the printing process where the paper absorbs and diffuses the ink there is always some distance from the maximum and minimum reflectance. Blurriness defines the distance between 10% and 90% of the dynamic threshold.

Raggedness is a property that defines the roughness of the printed line edge. While the ideal line edge is perfectly sharp and straight, the edges of the printed line usually show some deviation from the perfect line, due to ink spillage and diffusion, resulting in edge roughness. Hence, to measure raggedness, a fitted line is positioned at the dynamic threshold of 60% and the standard deviation of the residuals from this fitted line is a measure of raggedness.

Table 2 (part 1): 3D surface plot diagrams of printed letters on commercial and laboratory paper substrates

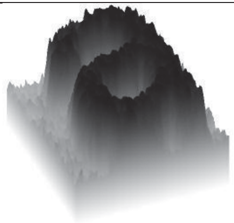
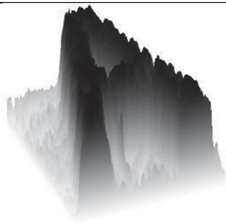
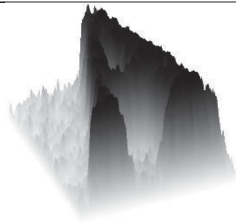
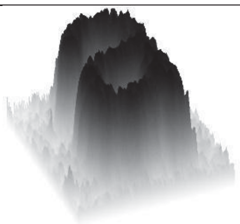
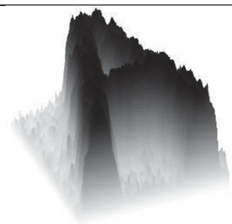
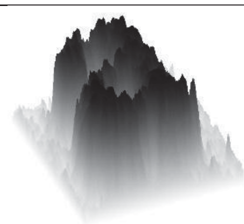
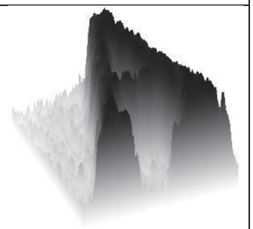
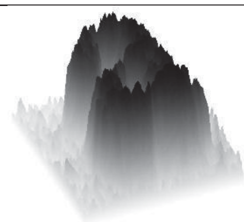
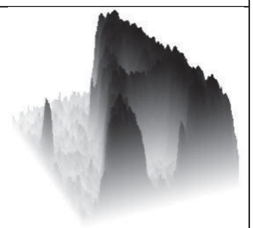
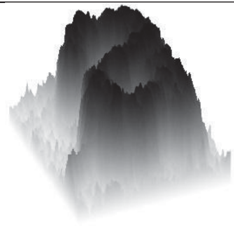
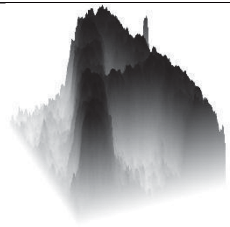
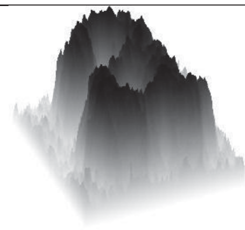
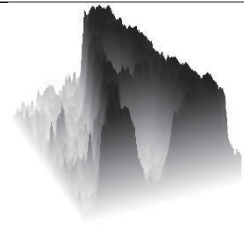
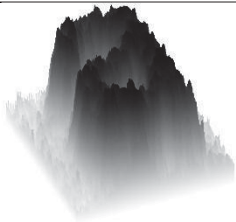
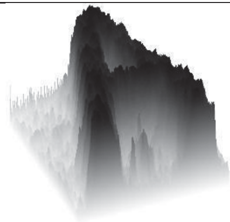
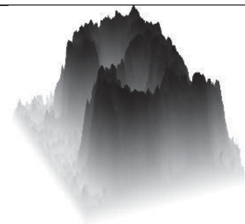
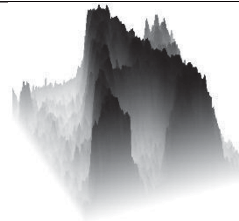
Paper substrate	Arial		Times New Roman	
	lowercase	uppercase	lowercase	uppercase
K				
N				
3NW				

Table 2 (part 2): 3D surface plot diagrams of printed letters on commercial and laboratory paper substrates

3NB				
3NTR				

The quality and homogeneity of the printed letters was first determined by a visual examination of the letter samples. Using ImageJ software, images of the printed letters, obtained by PIAS II microscope, were converted into 3D surface plots where the highest peaks determine the darkest coloration. Table 2 shows that the printed surface of the letters is relatively non-uniform but the significant difference between commercially and laboratory produced papers was not observed. Comparing only the laboratory produced papers with the addition of 30% straw pulp (3NW, 3NB, 3NTR) and without straw pulp of any cereal type (N) also shows no significant difference. A visual examination of the two typefaces, Arial and Times New Roman, shows that letters printed in the Arial sans-serif typeface have a slightly better uniformity of print with less protrusion peaks than the serif typeface Times New Roman.

After a visual examination, the parameters of line edge and print quality: fill, contrast, blurriness, and raggedness, were measured by the PIAS II device on ten sample areas of printed letter samples.

3. RESULTS AND DISCUSSION

Uniformity of the prints was further examined by analysing the fill and contrast parameters. Values in Table 3 show slightly greater or equal results for the fill parameter of Arial typeface for all printing substrates. The largest difference was measured in control (commercially produced) paper substrate K with 0.97 for Arial, and 0.94 for Times New Roman. Laboratory produced paper substrates had smaller or no difference between fill parameter for Arial and Times New Roman typefaces, regardless of the type of straw pulp added to the recycled newsprint pulp. The paper substrate with the addition of 30% barley pulp showed no difference in the fill parameter (0.96) for the two analysed typefaces. The parameter of contrast between the printed letter and the surrounding background field i.e., printing substrate, also showed largest values for the Arial typeface on all printing substrates. Similar to the fill parameter, the largest difference of contrast value was measured on commercial control paper substrate K, while the differences were somewhat smaller on laboratory produced paper substrates.

Table 3 (part 1): Average measured values and standard deviations of fill and contrast parameters on all printing substates for Arial and Times New Roman typefaces

Printing substrate / typeface			Fill	Contrast
K	Arial	avg	0.97	0.95
		stdev	0.08	0.05
	Times New Roman	avg	0.94	0.91
		stdev	0.09	0.06

Table 3 (part 2): Average measured values and standard deviations of fill and contrast parameters on all printing substates for Arial and Times New Roman typefaces

N	Arial	avg	0.96	0.92
		stdev	0.09	0.06
	Times New Roman	avg	0.95	0.89
		stdev	0.09	0.06
3NW	Arial	avg	0.97	0.92
		stdev	0.06	0.04
	Times New Roman	avg	0.96	0.89
		stdev	0.08	0.05
3NB	Arial	avg	0.96	0.91
		stdev	0.07	0.04
	Times New Roman	avg	0.96	0.89
		stdev	0.09	0.06
3NTR	Arial	avg	0.97	0.90
		stdev	0.07	0.04
	Times New Roman	avg	0.95	0.88
		stdev	0.09	0.05

The parameters of blurriness and raggedness help us to determine the degree to which the ink diffused and spread during the printing process due to the paper absorbance, ink viscosity and other printing variables. A higher deviation from the ideal straight, sharp edge of the line means a reduced quality of line reproduction. As visible in the Figure 1, the measurement of the blurriness parameter shows that the letters printed on the commercial paper K had lowest measured blurriness of the line edges, which was expected due to the processing of the commercial paper that improves the smoothness. Smoother paper surface is related to smaller ink deformations. The unprocessed surface of the laboratory produced paper substrates results in a slightly higher blurriness of the letter edges. The paper substrates with added straw pulp (3NW, 3NB, 3NTR) showed no significant difference compared to the laboratory paper substrate without added straw pulp (N). When comparing the two typefaces, Arial and Times New Roman, the prints on laboratory produced papers show slightly lower blurriness on Times New Roman but without significant value, while commercial paper shows a lower blurriness on Arial.

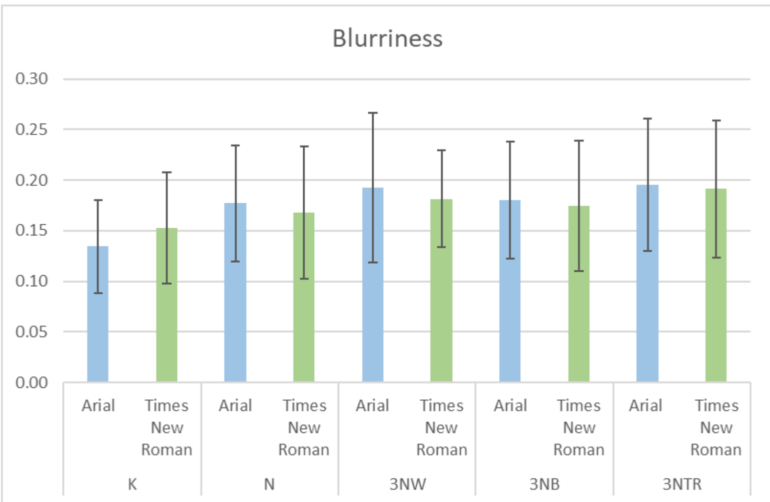


Figure 1: Comparison of blurriness values of letters printed in Arial and Times New Roman typeface on commercial and laboratory produced paper with and without straw pulp

Values measured for the raggedness parameter are presented in Figure 2. The results do not show consistency as with the measurements of blurriness parameter. Regarding the prints on commercial vs. laboratory paper substrate, the letter printed in Arial on sample K had a smaller raggedness value (0.0262) compared to Times New Roman typeface (0.0441). Value of raggedness had no correlation with the printing substrate or the means of production. The printing substrate with added triticale pulp had the lowest measured values of raggedness compared to other printing substrates including both typefaces (0.0239 for Arial and 0.0254 for Times New Roman). The highest raggedness was measured on printing substrates with barley pulp for both typefaces (0.0528 for Arial and 0.0547 for Times New Roman). The prints on the paper substrates with the addition of wheat straw pulp measured similar values as the control and reference paper substrates K and N, which were produced from recycled wood pulp only.

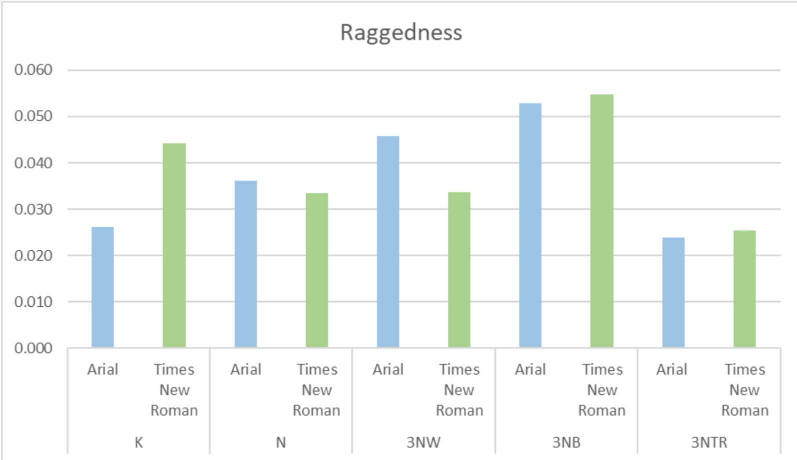


Figure 2: Comparison of raggedness values of letters printed in Arial and Times New Roman typeface on commercial and laboratory produced papers with and without straw pulp

4. CONCLUSIONS

The quality of reproduction is of great importance in conveying information from the printed text to the viewer. The packaging industry and graphic design depend on the clarity of printed text and graphics to enhance the visibility and legibility of the intended message. Therefore, choosing the right paper substrate and printing techniques is as important as choosing the right typography and size of legible text. Paper substrates with the addition of alternative cereal straw material such as wheat, barley or triticale pulp have been shown in previous research to reproduce colour prints with similar reliability as those produced only from recycled wood pulp. Research has also shown that the quality of line reproduction has similar characteristics compared to commercial papers. In this research, based on the evaluation of the printed text quality, it can be concluded that:

- commercially and laboratory produced papers with and without addition of straw pulp show similar results in edge blurriness measurements, with slightly but insignificantly higher values for papers with the addition of straw pulp.
- raggedness measurements show less consistency; the lowest values were determined for papers containing triticale pulp, and the highest values for papers with barley pulp. Papers with the addition of wheat pulp showed similar values as commercially and laboratory produced papers without added straw pulp.
- fill and contrast measurements were similar in laboratory produced papers regardless of the paper substrate composition, with values greater for the Arial sans-serif typeface than for the Times New Roman serif typeface.

Although the surface of the laboratory produced papers was not additionally processed, smoothed, or coated, the results show that the quality of the printed text is acceptable when compared to commercially produced paper without the addition of straw pulp. Suggestions for improving the quality of printed text can be made by smoothing or coating the surface of the papers, reducing the absorbance and roughness of the printing surface.

5. ACKNOWLEDGEMENTS

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