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ANALYSIS OF THE QUALITY OF REPRODUCTION ON A GRAPHIC PRODUCT WITH MORE POSITIVE ENVIRONMENTAL ASPECTS

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Abstract
In recent years, there has been a growing trend worldwide to replace traditional wood fibres as a raw material for paper production with non-wood fibres. By using alternative sources of cellulose fibres for paper production, such as cereal straw, deforestation is reduced, which is one of the positive environmental aspects of producing a of a graphic product with such a composition. Another positive environmental aspect of the graphic product produced in this way is the elimination of the bleaching process in paper production, which has a positive effect on reducing chemical pollution. In the paper manufacturing process, the paper used for printing usually goes through a bleaching process that reduces the yellowish tone of the paper and increases light emission, brightness and contrast. However, looking at the matter from a different perspective, especially for small-scale production, the process of paper whitening can also be done differently, namely by coating the paper with a white pigment. The aim of this research was to analyse whether it is possible to achieve the same reproduction quality with one or two layers of titanium dioxide on non-wood paper substrates as on commercially available standard paper type 7 according to ISO 12647. The reproduction quality was tested by analysing the reproduction of lines printed in different sizes using piezo inkjet technology. Double-coated samples achieved 2.6 % better results than single-coated samples. The result closest to the reference sample PS7 was obtained with a paper containing 10 % wheat straw and coated with two layers of titanium dioxide. The results obtained show that the proportion of wheat pulp does not lead to a deterioration in the quality of line reproduction in the prints.
Keywords: *cereal straw, coating, paper, reproduction quality, titanium dioxide*

Introduction

Paper has played an extremely important role in human society for centuries. Before the advent of digital technology, paper was the most important medium for communicating, storing information and writing. During the last few centuries, the paper industry has evolved considerably due to the increasing demand for paper products (Ashori, 2006). Softwood and hardwood trees are mostly used for the production of wood pulp, which serve as the main raw materials for paper production. Global paper production capacity is expected to reach 510 million tonnes by 2025, driven by increasing demand for packaging, printing, and writing paper. Paper production is a complex and resource-intensive process of converting raw materials such as wood, waste paper or other plant fibres into high-quality paper products. The paper manufacturing process comprises several stages: pulping, cleaning, forming, sorting, drying and finishing, each of which has an important role in determining the quality and properties of the final product. This process also generates significant waste, including water, chemicals and paper sludge, which can have a significant impact on the environment if not handled properly. At each of these stages, the pulp mixture undergoes various treatments to improve its properties such as strength, gloss and smoothness to produce the final paper product. The paper production process can vary depending on the intended use of the paper, as different types of paper require specific properties and characteristics. The bleaching process is not common for all types of papers. In some papers it is used to improve the brightness and whiteness of the paper. Bleaching removes lignin residues and other impurities from the fibres, which can cause the paper to turn yellow over time (Bajpai, 2021; Samani, 2023). In the past, the process of bleaching paper was also very popular, whereby the paper was exposed to the sun even after cooking and washing (Brückle, 2009). There are several bleaching processes in the paper industry: elemental chlorine bleaching, chlorine dioxide bleaching, oxygen delignification, peroxide bleaching, and ozone bleaching. In elemental chlorine bleaching, gaseous chlorine is used to bleach the pulp. Although this method is effective, it produces harmful by-products such as dioxins and furans, which are toxic and remain in the environment for a long time. Chlorine dioxide bleaching uses chlorine dioxide gas, which is less harmful than elemental chlorine. Chlorine dioxide is a strong oxidizing agent that breaks down lignin and other impurities in the pulp, while oxygen gas is used for this purpose in the oxygen delignification process. This method is less effective but produces fewer harmful by-products. Efficient and environmentally friendly methods are peroxide bleaching, which uses hydrogen peroxide, and ozone bleaching. This method uses ozone gas, a powerful oxidizing agent that breaks down lignin and other impurities in the pulp (Strunk, 2012). The process of producing a white paper surface can also be carried out in another way, namely by coating the paper separately with a white pigment.

The aim of this research was to analyse whether it is possible to achieve the same reproduction quality with one or two layers of titanium dioxide on non-wood paper substrates as on commercially available standard bleached paper type 7 according to ISO 12647. The reproduction quality was tested by analysing the reproduction of lines printed in different sizes with UV LED piezo inkjet technology.

Materials and methods

This research was carried out in four steps: conversion of straw into cellulose pulp; production of paper with and without straw pulp; coating of laboratory papers; printing of the test pattern with lines; analysis of line reproduction and assessment of the print quality. To obtain cellulose fibres, the straw was collected after the wheat harvest, cleaned, cut by hand and processed into pulp using the soda method (Plazonic et al., 2016). The resulting unbleached pulp from wheat straw was added to the pulp from recycled wood fibres in different proportions to produce a paper under laboratory conditions using a Rapid Köthen sheet former (FRANK-PTI GmbH, Birkenau, Germany) according to EN ISO 526 9-2:2004 (Bates et al., 2020). Table 1 shows the composition and labelling of the laboratory papers produced. All laboratory papers have a diameter of 20 cm and a weight of approx. 42.5 g/m^2.

Table 1. Composition and abbreviations of laboratory papers

Abbreviations	Composition
N	100% recycled wood pulp
10NP	10% wheat pulp + 90% recycled wood pulp
20NP	20% wheat pulp + 80% recycled wood pulp
30NP	30% wheat pulp + 70% recycled wood pulp

In order to achieve the same degree of whiteness as commercially bleached papers, the laboratory papers were coated with one or two layers. The TiO_2-based coating was applied separately in full-tone on laboratory papers using a digital UV LED piezo inkjet printing machine, a Roland VersaUV LEC-300. The abbreviations of the paper substrates used and their whiteness values are summarized in Table 2. The results of the whiteness measurement with the eXact spectrophotometer, X-rite, show that the values obtained are within the recommendations of the ISO 12647 standard for all uncoated papers in group 7 (ISO 12647-2). The composition of the TiO_2-based coating used and the whiteness, brightness, yellowness and opacity values obtained are available in our previous research (Radić Seleš et al., 2020).

Table 2. Abbreviations of the paper substrates

Abbreviations	Samples	Whiteness (ASTM 313)
Nx1	sample N with one layer of TiO_2	46.34
Nx2	sample N with two layers of TiO_2	63.74
10NPx1	sample 10NP with one layers of TiO_2	47.84
10NPx2	sample 10NP with two layers of TiO_2	65.17
20NPx1	sample 10NP with one layers of TiO_2	42.86
20NPx2	sample 10NP with two layers of TiO_2	63.48
30NPx1	sample 10NP with one layers of TiO_2	35.91
30NPx2	sample 10NP with two layers of TiO_2	60.63
PS7	commercial paper ISO 12647 type PS7	78.94

In the next step, the test pattern with desired line widths (Table 3) was printed on coated laboratory papers as well on the reference sample PS7, which is commercially bleached paper type 7 according to the ISO 12647-2 standard. The test pattern was printed with the same printing machine (Roland VersaUV LEC-300) with which the coating was also applied to the samples. After printing the test pattern on the eight obtained coated laboratory papers and the commercial paper PS7, an analysis of the line reproduction was carri ed out with the PIAS-II image analysis device according to the ISO 13660 standard (ISO 13660). The lines of different widths are printed as shown in Table 3. The thinnest line is labelled with the number 1, while the thickest line is labelled with the number 6.

Table 3. The test pattern (desired line width and labels)

	Desired line widths (mm)	Labels
	0.737	No. 6
	0.423	No. 5
	0.339	No. 4
	0.254	No. 3
	0.169	No. 2
	0.085	No. 1

Results and discussion

For a better comparison of printed lines of the desired width sizes, Tables 4 to11 show the measured values of the reproduced line widths on coated laboratory papers and the measured widths on PS7 commercial paper as well as their differences in percentages.

a)

b)

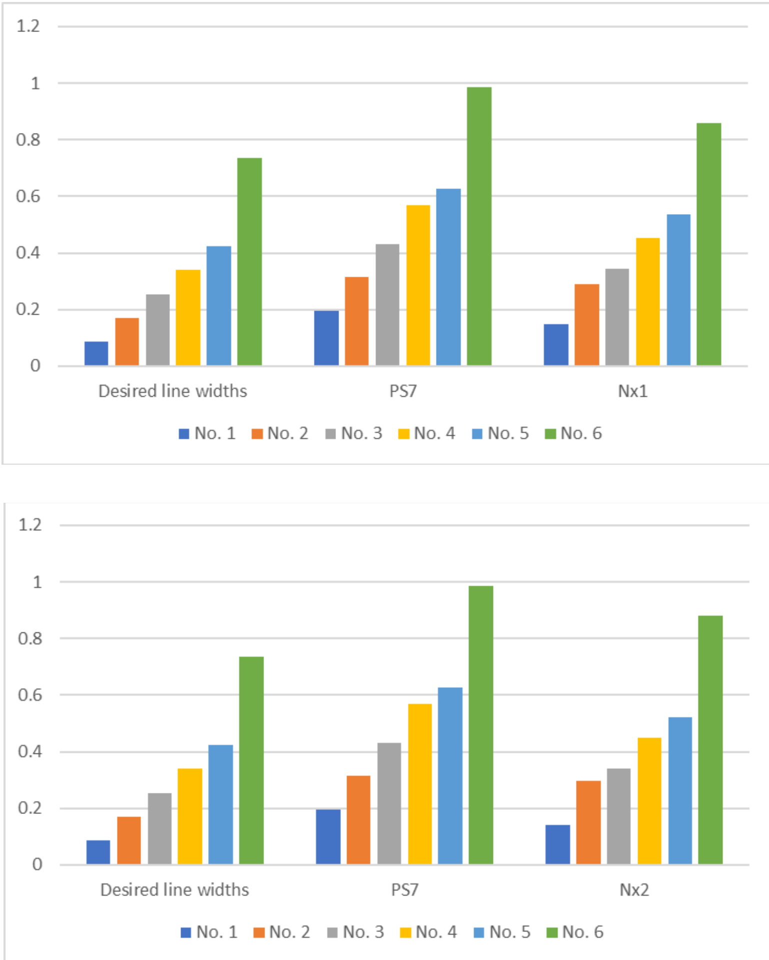


Figure 1. Line width on laboratory paper (in millimetres (mm)) made from 100% recycled wood pulp (N) coated with one layer of TiO_2 *(Nx1) and two layers of* TiO_2 *(Nx2) in comparison with the reference sample (PS7)*

Table 4. Measured line widths printed on laboratory paper with wood pulp coated once (Nx1), desired line widths and measured lines on reference paper PS7 and their differences

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Desired line widths (mm)	0.085	0.169	0.254	0.339	0.423	0.737
PS7	0.196	0.316	0.431	0.567	0.625	0.984
Nx1	0.150	0.290	0.345	0.452	0.536	0.858
Difference Nx1 vs PS7 (mm)	0.046	0.026	0.086	0.115	0.089	0.126
Difference Nx1 vs PS7 (%)	23.5%	8.2%	20.0%	14.2%	20.3%	12.8%

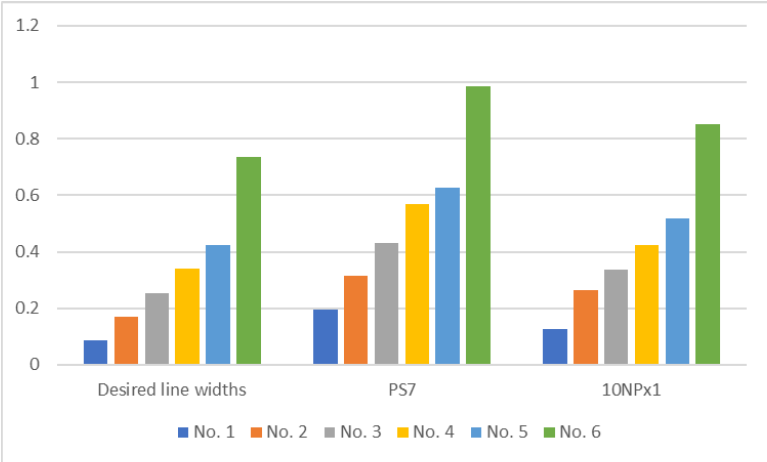
Table 5. Measured line widths printed on laboratory paper with wood pulp coated twice (Nx2), desired line widths and measured lines on reference paper PS7 and their differences

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Desired line widths (mm)	0.085	0.169	0.254	0.339	0.423	0.737
PS7	0.196	0.316	0.431	0.567	0.625	0.984
Nx2	0.141	0.295	0.342	0.450	0.523	0.879
Difference Nx2 vs PS7 (mm)	0.055	0.021	0.089	0.117	0.102	0.105
Difference Nx2 vs PS7 (%)	28.1%	6.6%	20.6%	20.6%	16.3%	10.7%

From the results of the reproduced line analysis, it can be seen that the single-coated wood fibre laboratory paper achieved greater changes in the reproduction of the thinnest line compared to the thicker lines when set side by side with commercial PS7 paper (Figure 1a). The same paper with two layers of titanium dioxide coating achieved a much smaller change in the thicker lines than with one coating, while the thinnest line showed a much larger increase (Figure 1b).

The smallest differences in line width between commercial PS7 and wood fibre paper (N) with one or two layers of TiO_2 were achieved in the reproduction of line No. 2. For all reproduced line widths, it can be seen that a smaller increase than the desired value was achieved for the samples coated with titanium dioxide compared to the commercially bleached paper PS7.

a)



b)

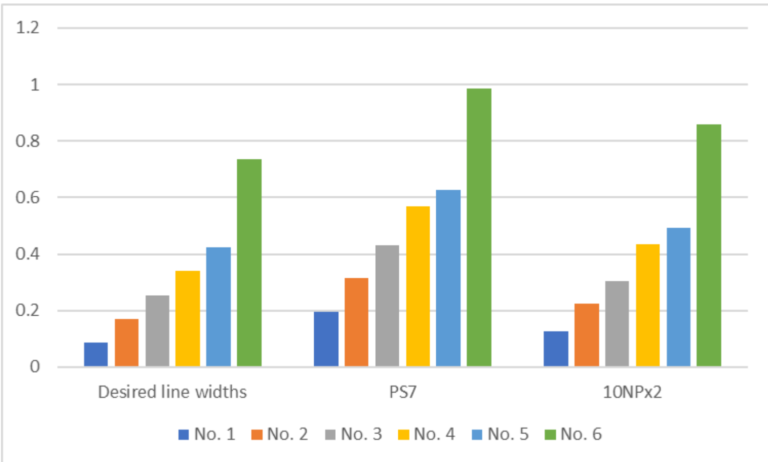


Figure 2. Line width on laboratory paper (in millimetres (mm)) made with 10% wheat pulp (10NP) coated with one layer of TiO_2 *(10NPx1) and two layers of* TiO_2 *(10NPx2) in comparison with the reference sample (PS7)*

Table 6. Measured line widths printed on laboratory paper with 10% wheat pulp coated once (10NPx1), desired line widths and measured lines on reference paper PS7 and their differences

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Desired line widths (mm)	0.085	0.169	0.254	0.339	0.423	0.737
PS7	0.196	0.316	0.431	0.567	0.625	0.984
Nx2	0.126	0.265	0.335	0.424	0.519	0.850
Difference 10NPx1 vs PS7 (mm)	0.070	0.051	0.096	0.143	0.106	0.134
Difference 10NPx1 vs PS7 (%)	35.7%	16.1%	22.3%	25.2%	17.0%	13.6%

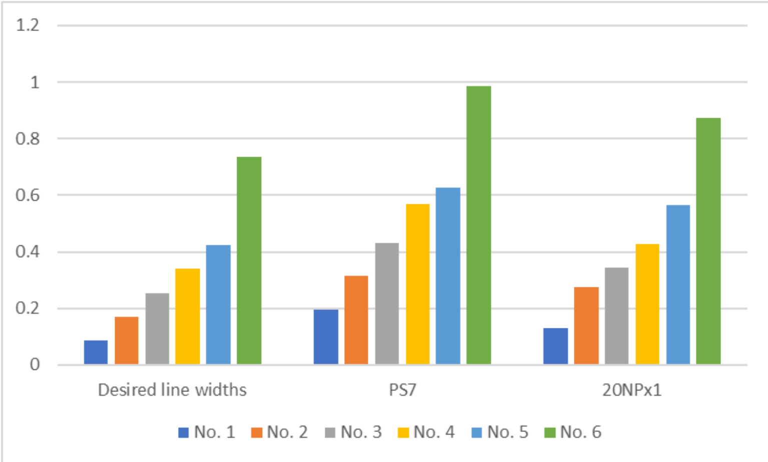
Table 7. Measured line widths printed on laboratory paper with 10% wheat pulp coated twice (10NPx2), desired line widths and measured lines on reference paper PS7 and their differences

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Desired line widths (mm)	0.085	0.169	0.254	0.339	0.423	0.737
PS7	0.196	0.316	0.431	0.567	0.625	0.984
10NPx2	0.128	0.224	0.305	0.433	0.492	0.857
Difference 10NPx2 vs PS7 (mm)	0.068	0.092	0.126	0.134	0.133	0.127
Difference 10NPx2 vs PS7 (%)	34.7%	29.1%	29.2%	23.6%	21.3%	12.9%

The samples containing 10% wheat pulp (10NP) show that the reproduction of thicker lines is better than that of thinner lines if they are coated with one or two layers of titanium dioxide coating (Figures 2 a, b), that is, there is less difference between commercial paper PS7 and coated paper.

Namely, a smaller increase in line width is observed for papers with 10% wheat pulp coated with TiO_2 compared to commercial bleached wood paper (Tables 6 and 7).

a)



b)

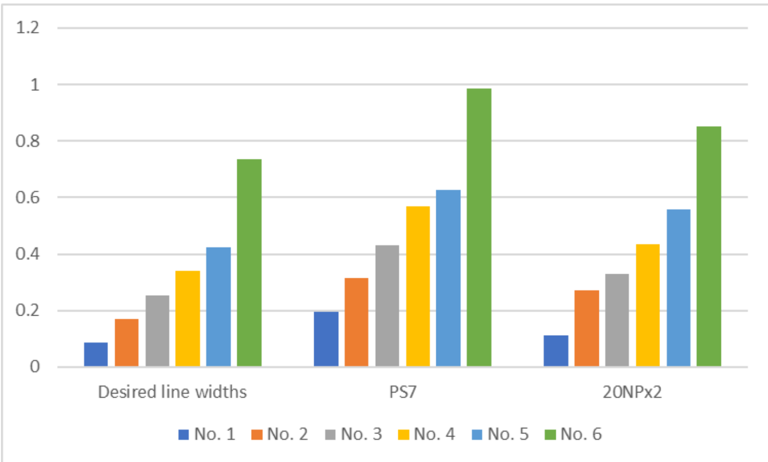


Figure 3. Line width on laboratory paper (in millimetres (mm)) made with 20% wheat pulp (2NP) coated with one layer of TiO_2 (20NPx1) and two layers of TiO_2 (20NPx2) in comparison with the reference sample (PS7)

Table 8. Measured line widths printed on laboratory paper with 20% wheat pulp coated once (20NPx1), desired line widths and measured lines on reference paper PS7 and their differences

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Desired line widths (mm)	0.085	0.169	0.254	0.339	0.423	0.737
PS7	0.196	0.316	0.431	0.567	0.625	0.984
20NPx1	0.129	0.276	0.343	0.426	0.565	0.873
Difference 20NPx1 vs PS7 (mm)	0.067	0.040	0.088	0.141	0.060	0.111
Difference 20NPx1 vs PS7 (%)	34.2%	12.7%	20.4%	24.9%	9.6%	11.3%

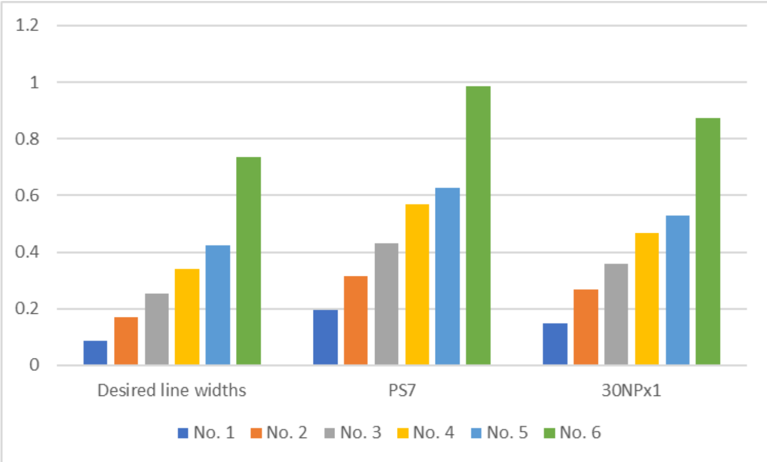
Table 9. Measured line widths printed on laboratory paper with 20% wheat pulp coated twice (20NPx2), desired line widths and measured lines on reference paper PS7 and their differences

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Desired line widths (mm)	0.085	0.169	0.254	0.339	0.423	0.737
PS7	0.196	0.316	0.431	0.567	0.625	0.984
20NPx2	0.113	0.273	0.330	0.433	0.557	0.853
Difference 20NPx2 vs PS7 (mm)	0.083	0.043	0.101	0.134	0.068	0.131
Difference 20NPx2 vs PS7 (%)	42.3%	13.6%	23.4%	23.6%	10.9%	13.3%

Looking at the results of coated laboratory paper with 20% non-wood pulp (Figures 3a, b), it is evident that the reproduced line widths achieved are very similar to the values measured on coated laboratory paper made of wood pulp.

Better reproduction can be seen on coated papers compared to commercial paper PS7, the increase in line width is smaller.

a)



b)

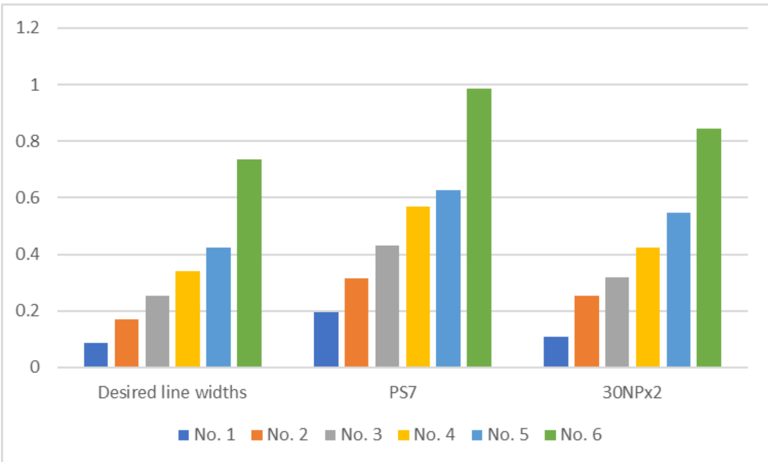


Figure 4. Line width on laboratory paper (in millimetres (mm)) made with 30% wheat pulp (3NP) coated with one layer of TiO_2 *(30NPx1) and two layers of* TiO_2 *(30NPx2) in comparison with the reference sample (PS7)*

Table 10. Measured line widths printed on laboratory paper with 30% wheat pulp coated once (30NPx1), desired line widths and measured lines on reference paper PS7 and their differences

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Desired line widths (mm)	0.085	0.169	0.254	0.339	0.423	0.737
PS7	0.196	0.316	0.431	0.567	0.625	0.984
30NPx1	0.149	0.269	0.360	0.467	0.530	0.872
Difference 30NPx1 vs PS7 (mm)	0.047	0.047	0.071	0.100	0.095	0.112
Difference 30NPx1 vs PS7 (%)	24.0%	14.9%	16.5%	17.6%	15.2%	11.4%

Table 11. Measured line widths printed on laboratory paper with 30% wheat pulp coated twice (30NPx2), desired line widths and measured lines on reference paper PS7 and their differences

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Desired line widths (mm)	0.085	0.169	0.254	0.339	0.423	0.737
PS7	0.196	0.316	0.431	0.567	0.625	0.984
30NPx2	0.108	0.252	0.320	0.422	0.547	0.844
Difference 30NPx1 vs PS7 (mm)	0.088	0.064	0.111	0.145	0.078	0.140
Difference 30NPx2 vs PS7 (%)	44.9%	20.3%	25.8%	25.6%	12.5%	14.2%

The results, which were measured on coated laboratory samples with 30% non-wood pulp (Figure 4ab, Tables 10 and 11), show that all samples exhibit very similar behaviour regardless of the proportion of wheat pulp.

Conclusions

The aim of this research and the main question is whether laboratory paper samples with wheat pulp and titanium dioxide coatings can match or even exceed the test results for commercial paper. The short answer is yes.

- All samples with one or two layers of titanium dioxide coatings consistently achieve results closer to the target values (defined by pattern) than the bleached reference paper PS7.

- Samples with two layers of titanium dioxide coatings achieved results closer to the target values compared to single coated samples.
- On average, samples with double coating achieved 2.6% better results than samples of the same composition coated with one coating layer. Therefore, the use of only one layer of TiO_2 coating is completely sufficient for less demanding reproductions.
- The result of reproduced line widths closest to the target value was achieved for coated laboratory paper with two coatings containing 10% non-wood fibres (10NPx2).

Based on the obtained results the proportion of non-wood pulp does not lead to a deterioration in the quality of line reproduction on the prints.

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