Rubbing stability of printed innovative paper substrates containing cereal straw pulp

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Abstract

Paper is one of the most important materials for packaging and the demand for this material is constantly increasing. The printing and packaging industries are researching alternative sources of fibre, to produce more environmentally friendly paper without compromising quality. As a packaging material, paper must meet high strength requirements, and it has to exhibit acceptable surface properties to preserve the printing quality. This research had two objectives: to produce paper made from pulp of recycled fibre reinforced with virgin straw fibre and to evaluate the print quality on such papers. Straw pulp used for this purpose was obtained from three cereal crops: wheat, barley, and triticale. The paper produced was printed by using five printing techniques. Rubbing stability was evaluated by the difference in colour and reflectance spectra before and after performing rub tests and a comparison was made for the best interaction of paper and ink determined by the printing technique. For the prints with the highest colour difference after the rub test, the surface of the rub test receptor (uncoated recycled paper) was examined for signs of ink transfer during the test and the areas of transferred ink coverage were calculated on their processed microscopic images.

Keywords: alternative fibre sources; durability; paper production; printing techniques; UV-curable black inks.

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1. INTRODUCTION

Packaging industry is rapidly developing, and its further growth is expected in the coming years [1]. At the same time, this industry sector is turning towards sustainable and environmentally friendly packaging solutions. Today, the ecological aspect of packaging is considered even more important than the economic one [2]. The evolving regulatory environment, increasing competition and changing consumer preferences for certain packaging solutions are just some of the challenges facing the packaging industry [3]. Therefore, substantial research is needed in this sector of printing industry to provide the market with sustainable, environmentally friendly and, at the same time, high-quality packaging that does not jeopardize quality of the packaged product or the environment that we leave as a legacy to future generations. One of the most important trends that will undoubtedly shape the future of packaging industry is the shift towards paper-based packaging solutions. Considering that paper packaging, unlike plastic, is not only biodegradable, but also recyclable, it represents a more sustainable option that is in line with the growing preferences for sustainable and environmentally friendly packaging options [4]. When it comes to packaging recycling, fibre-based packaging has the highest recycling rate in Europe amounting to 82 % and the goal is to reach 90 % recycling rate for fibre-based packaging by 2030 [5]. In general, the main raw materials used in pulp and papermaking industry can be classified into three categories: wood, non-wood, and non-plant (mainly waste paper) [6]. However, it should be kept in mind that wood as a forest resource is still the main source of cellulose fibres in the paper industry. Therefore, sustainably managed forests are crucial for our environment, as well as the transition to other lignocellulosic raw materials, which will reduce the amount of virgin wood fibres for the paper industry needs while providing the needed length and quality of the cellulose fibres. The recycling process incorporates removal of ink from printed papers to produce a fibrous

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material called recycled pulp from which fibres are reprocessed and incorporated into new products, which provides the added value. Recycled pulp, however, is a mixture of different types of waste paper and varies in composition from source to source and from day to day from a single source. Variability of pulp raw materials which is increasing as the proportion of recycled fibres increases, is a very common problem for the packaging industry worldwide. It is therefore constantly faced with the challenge of ensuring a satisfactory strength of packages despite the increase in the recycled paper content as the main fibrous component. Nowadays, packaging grade papers contain 60-100 % recycled fibres [7, 8]. Recycled fibres tend to be broken or damaged and they have different physical properties than virgin fibres (*e.g.*, micro-fibrils on the fibre surface more likely tend to collapse) resulting in weaker inter-fibre bonding and consequently lower strength of paper or paper board products [7]. With each cycle of the recycling process, the fibres become shorter and more damaged, limiting their potential uses. To provide the crucial strength properties for paper packaging made from recycled fibres, a certain amount of fresh virgin fibres has to be incorporated into the pulp [9]. Although waste paper is the main raw material for paper production, it should be emphasized that without fresh virgin fibres, utilization of the recycled fibres would not be possible. Therefore, it is important to find alternative sources of virgin fibres for printing and packaging industries, to produce more environmentally friendly paper without compromising quality. Selection of packaging materials is very complex, as they have to fulfil various packaging functions, such as protecting the contents, conveying information about the products, and facilitating their transportation. Only the right combination of materials allows benefits such as longer durability and better protection against external damage. Research in this paper focuses on the possibility of substituting virgin wood fibres with the aim of refining recycled pulp in the production of packaging paper intended for printing. Evaluation of the possibility for using virgin fibres from cereal straw for this purpose was carried out after printing the produced innovative paper substrates with the addition of cereal straw pulp. Five printing techniques commonly utilized in the printing industry (digital, flexographic, offset, gravure, and screen printing) were used followed by exposure of the prints to rubbing at low pressure as a simulation of handling of this packaging.

2. MATERIALS AND METHODS

The research was conducted in four phases:

1. production of paper substrates on the laboratory scale with and without cereal straw pulp;
2. printing of paper substrates with UV-curable black inks by using five different printing techniques;
3. testing of rub resistance of the prints;
4. spectrophotometric measurements of the prints before and after the rub resistance tests to determine the difference in coloration.

2. 1. Production of paper substrates with cereal straw pulp

Circular paper substrates weighing 42.5±2.6 g/m^2 and 200 mm in diameter were produced in the laboratory by mixing recycled wood pulp from newsprint and unbleached wheat, barley, or triticale straw pulp in a weight ratio of 7:3 by a Rapid-Köthen sheet former (FRANK-PTI, Austria) according to the standard EN ISO 5269-2:2004 [10]. Straw was used as an alternative raw material to obtain cellulose pulps. Straw pulp of each crop type was prepared in laboratory conditions after straw was collected from fields in central Croatia immediately after harvest. In contrast to wood materials, there is less lignin in wheat straw [11] resulting in a more open structure that is more susceptible to reactions with alkalis. Sodium hydroxide used in soda pulping easily dissolves phenolic lignin structures. Therefore, alkaline pulping process was chosen as it provided straw pulp with good strength properties [12] which was needed for the purpose of this research. Namely, in this research, virgin straw fibres were used with the aim of refining recycled fibres, which were increasingly shortened and damaged by repeated recycling processes. Before cooking, foreign materials and grains were removed, and the straw of each crop was chopped to a length of 1 to 3 cm. Each type of straw was cooked under the same process conditions, which are kept constant during the soda pulping process [13]. Wheat (W), barley (B) and triticale (TR) straw was cooked separately by placing the materials in autoclave along with the classical reagent (sodium hydroxide) at a 10:1 liquid/solid ratio and pulped by using the reagent concentration of 16 %, at a temperature of 120 °C and a pressure of 170 kPa for 60 min.

After pulping, the cooked material was washed to remove residual cooking liquor and fiberized in a Holländer Valley mill (AB Lorentzen & Wettre, Sweden) at 500 rpm for 40 min. The pulp was drained and allowed to dry to a moisture content of about 10 % at room temperature.

In total, at laboratory scale, four different types of paper substrates were produced with and without cereal straw pulp (used as a reference and marked with 100N). Table 1 lists abbreviations and contents of the paper substrates produced according to the type of pulp used.

Table 1. Laboratory produced paper substrates

Abbreviation	Amount of recycled wood pulp fibres, %	Amount of straw pulp fibres, % (cereal type)
100N	100	0
70N30W	70	30, wheat
70N30B	70	30, barley
70N30TR	70	30, triticale

2. 2. Printing of paper substrates with UV-curable inks

Printing of paper substrates was conducted by five common printing techniques to observe the interaction between inks, printing conditions and the produced paper substrates with added cereal straw pulp. All paper substrates were printed in full tone with black UV-curable inks that use polymerization of the ink as the drying (curing) technique when irradiated with UV light.

2. 2. 1 Digital ink-jet printing

Digital ink-jet printing was carried out on an EFI Rastek H652 UV-curable printer (EFI, USA, CA) with EFI propriety ink. Printing quality was set on high quality mode (8 passes) with a speed of 12.1 m^2/h and a resolution of 600×600 dpi. Fast drying was performed during printing under two mercury-based UV lamps with the power of 700 W.

2. 2. 2 Offset printing

Prints by offset printing technique were obtained on a Prüfbau multipurpose printability testing machine (Prüfbau, Germany) with SunCure Starluxe low migration UV-curable inks (Sun Chemical, USA, NJ). Printing conditions were set at a temperature of 23 °C and a relative humidity of 50 % with the printing speed of 0.5 m/s and a pressure of 600 N. Drying was performed immediately after printing by a Technigraf Aktiprint L 10-1 dryer (Technigraf, Germany), UV-C tube with a light source power of 120 W/cm and an intensity of 60 %.

2. 2. 3 Flexographic printing

Flexographic prints were made on an Esiproof (RK Print Coat Instruments Ltd, UK) laboratory device using UV-curable ink Solarflex Integra (Sun Chemical, USA, NJ) at a temperature of 23 °C and a relative humidity of 50 %. After printing, the prints were dried in the same manner as prints obtained by offset printing.

2.2.4. Gravure printing

Gravure printing was performed on a KPP Gravure system with (RK Print Coat Instruments Ltd, UK) with UV-curable ink Solarflex Integra (Sun Chemical, USA, NJ) at a temperature of 23 °C and a relative humidity of 50 %. Printing speed was 20 m/min, with using a 65 Shore impression roller and a 39.37 lines/cm engraving plate. Gravure prints were dried on the same device under the same drying conditions as for the offset and flexographic printing.

2. 2. 5. Screen printing

For screen printing, a semi-auto Shenzhen Juisun screen printing machine (Juisun, China) with a squeegee of a mechanical hardness of 75 Shore and a mesh line of 140 lines/cm was used. The prints (140×140 mm) were made with UltraGraph UVAR UV-curable inks (Marabu GmbH & Co.,Germany). All prints were printed at a temperature of 23 °C and a relative humidity of 50 %. After printing, the UV prints were dried in two passes by UV irradiation.

2. 3. Rub resistance testing of prints

One of the most important indicators of the quality of printed paper packaging is the stability to rubbing. Low quality prints have a tendency of smearing, scratching, or scuffing off the printed text or image when pressure or abrasion is applied [14], which is not acceptable for secondary packaging. Rubbing off is most noticeable in solid printed areas that come into contact with other surfaces [15] and the main factors affecting the amount of ink loss are the interaction between the ink and substrate, chemical composition of the ink, the drying process and the thickness of the applied ink layer [16]. Therefore, the goal was to obtain a similar ink layer thickness on solid areas on all paper substrates using different printing techniques. Yet, due to different ink transfer methods, it was impossible to obtain exactly the same ink layer thickness on each print. The rub resistance test was conducted by using a Hanatek T4 Rub and Abrasion Tester device (Rhopoint Instruments, UK) according to the standard BS 3110 [17]. Prior to testing, the prints were cut into round samples, 5 cm in diameter, and subjected to a pressure of 0.23 kg (0.5 lb) by 20, 40 and 60 circular movements at a speed of 1 rotation per second to simulate handling of this packaging. In addition to analysing spectrophotometric changes in the print after the rub stability test, surface of the opposite paper (receptor) used for rubbing was also analysed under microscope in order to determine the amount of printing ink transferred during the test. The microscopic images of the surface of the opposite paper taken by an optical microscope (Dino-Lite AM413T, Dino-Lite, Taiwan) after rubbing the print that had the least stability were analysed by ImageJ software, which was used to calculate the surface area of ink transferred to the opposite paper.

2. 4. Spectrophotometric measurements of prints

To evaluate the amount of the rubbed off ink from the surface of the paper substrate, the colour difference ΔE_{00}^* was calculated by using spectrophotometric measurements of CIE L*a*b* values before and after each cycle of rubbing tests. CIE L*a*b* values are chromatic scale values representing human colour perception, where L* value indicates the lightness, a* value indicates red-green component of a colour, and b* value indicates yellow-blue component of a colour. CIE L*a*b* values and spectral reflectance were measured by using the X-Rite SpectroEye device (X-Rite, USA, MI) under standard D50 illumination and a 2° observer. The measurements were performed on 50 printed paper substrates. The colour difference of the prints was calculated by equation (1) [18]:

$$\Delta E_{00}^{*}=\sqrt{\left(\frac{\Delta L'}{K_{L}S_{L}}\right)^{2}+\left(\frac{\Delta C'}{K_{C}S_{C}}\right)^{2}+\left(\frac{\Delta H'}{K_{H}S_{H}}\right)^{2}+R_{T}\left(\frac{\Delta C'}{K_{C}S_{C}}\right)\left(\frac{\Delta H'}{K_{H}S_{H}}\right)} \quad (1)$$

Tolerance for the acceptable colour difference in the printing industry is based on a small noticeable colour difference by a standard observer with the value of $\Delta E_{00}^* \leq 2$ [19].

To confirm the visual results, the transfer of ink that rubbed off the prints was calculated as the percentage of black pixels in the processed microscopic images, which were converted to bitmaps with a threshold of 50 %.

To determine the colour changes on prints more clearly, the spectral reflectance was also analysed. It was measured for the visible part of the spectrum from 400 to 700 nm wavelength in steps of 10 nm. The reflectance spectra of all prints before and after the rubbing test were measured, and the results of reflectance measurements for prints with the highest ΔE_{00}^* are presented as ΔR according to equation (2):

$$\Delta R = R_2 - R_1 \quad (2)$$

where: ΔR represents the spectral reflectance difference; R_2 represents the reflectance spectra after the rubbing test with 60 rotations, and R_1 represents the reflectance spectra before the rubbing test.

Statistical analysis of the obtained results was performed by calculating the one-way ANOVA method, with the probability value for significance ($p < 0.05$) using the OriginPro v2023b software.

3. RESULTS AND DISCUSSION

Since rub resistance is highly dependent on the thickness of the ink layer on the printing substrate, Table 2 shows the results of the optical ink density (D_i) of black prints with regard to the printing technique and the paper substrate.

Table 2. Optical ink density for printed paper substrates

Printed paper substrates	Optical ink density				
	Digital prints	Offset prints	Flexog. prints	Gravure prints	Screen prints
100N	0.96±0.01	0.96±0.01	1.14±0.01	1.18±0.02	1.24±0.03
70N30W	0.93±0.02	0.98±0.03	1.13±0.01	1.18±0.04	1.23±0.02
70N30B	0.90±0.01	1.02±0.02	1.13±0.01	1.07±0.03	1.22±0.01
70N30TR	0.91±0.02	1.01±0.02	1.10±0.01	1.10±0.06	1.27±0.04

The spectrophotometric colour difference calculated as ΔE_{00}* was used to describe the best interactions between the black UV-curable ink and the paper substrate when printing by using five most commonly used printing techniques (digital, offset, flexographic, gravure, and screen printing). Lower values of colour difference represent better adhesion of the ink to the surface of the paper substrate and thus the higher rub resistance. Figure 1 shows the colour difference obtained from prints for all 5 printing techniques after the 20, 40 and 60 rotations in the rubbing test.

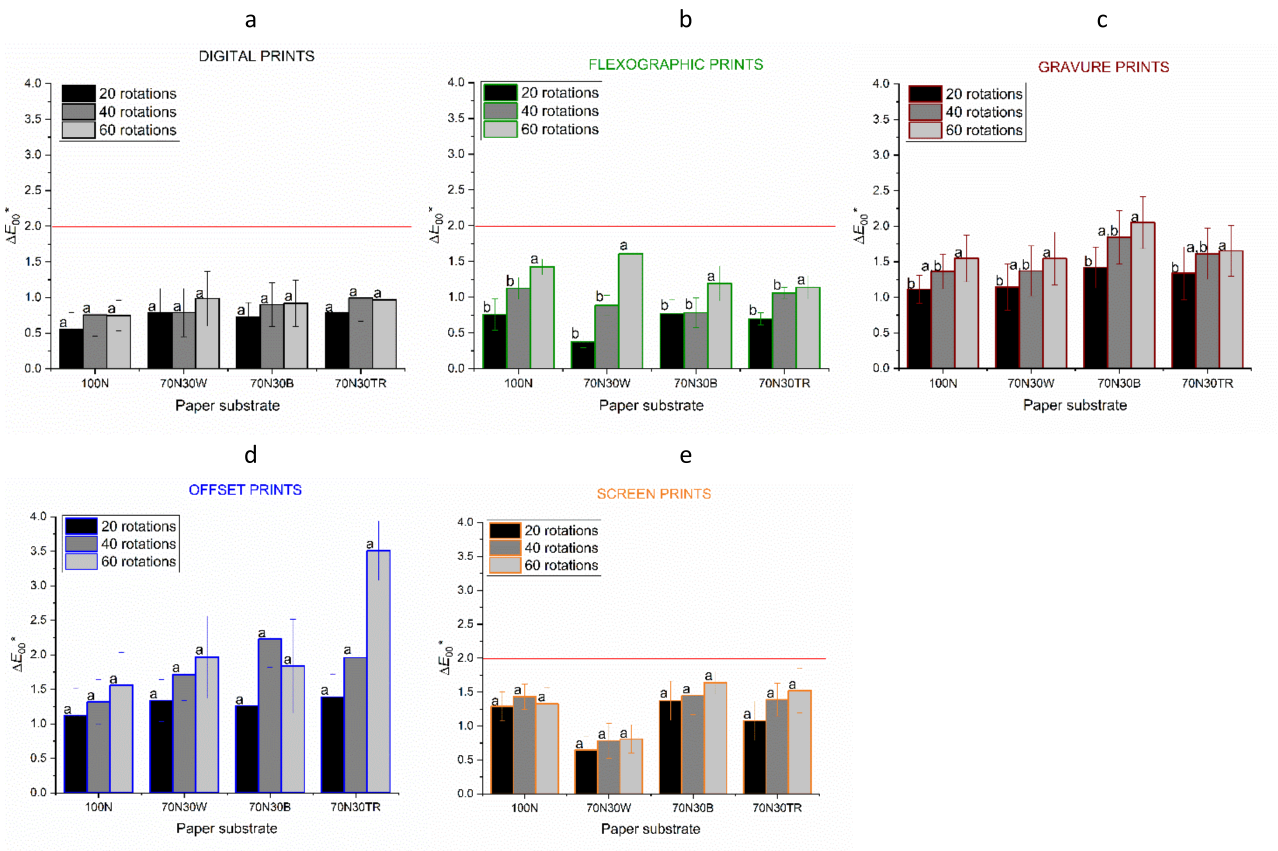


Figure 1. The colour difference (ΔE_{00}) of a) digital, b) flexographic, c) gravure, d) offset, and e) screen prints on paper substrates (100N, 70N30W, 70N30B, 70N30TR) after 20, 40 and 60 rotations in the rub resistance test; letters a and b designate statistically different values*

The rub stability, evaluated by the colour difference (ΔE_{00}*) calculated from CIE L*a*b* values before and after the rubbing tests, shows the lowest colour changes (ΔE_{00}* < 1) for digital prints on all printing substrates regardless of the type of pulp used (Fig. 1a) even after prolonged rubbing cycles (up to 60 rotations). Similarly low values are obtained for the reference paper 100N without added straw pulp, as well as papers with 30 % addition of wheat, barley, or triticale pulp. The ANOVA analysis resulted in a significance level (marked "b", Fig. 1) only for flexographic and gravure prints at rotations of 20 and 40, while for all other prints the results were not significantly different when the prints are observed under the same rubbing conditions. Rub tests at higher number of rotations (40 and 60) show stable values of ΔE_{00}* that are the same or with a negligible difference compared to the first iteration of the test with 20 rotations. The flexographic prints also show good stability (ΔE_{00}* < 0.76) to the initial impact of the rub resistance test of 20 rotations (Fig. 1b). The colour difference increases as the applied number of rubbing rotations is increased to 40 and 60 (ΔE_{00}* < 1.61). The gravure prints (Fig. 1c) show greater ΔE_{00}* (ranging from 1.11 to 1.42) after the initial test of 20 rotations, with a relatively low increase of ΔE_{00}* (less than 2.05) in further iterations of the rub resistance test. For offset prints, while the initial impact of rub resistance (20 rotations) is comparable to gravure prints (ΔE_{00}* ranging from 1.12 to 1.39), greater variance and colour difference are observed with increasing the number of test rotations (Fig. 1d). Screen prints show good rub resistance at the initial 20 rotations (ΔE_{00}* < 1.37) for all paper substrates, with the stable rub resistance under prolonged rubbing conditions (ΔE_{00}* < 1.63). The best results are evident for the paper substrates with the wheat straw pulp addition (70N30W). It is certainly important to emphasize that regardless of whether the prints were made on paper substrates without or with triticale pulp, they had shown sufficient rub resistance after a cycle of 60 rotations, indicating the difference in colour that only an experienced observer can perceive. This is in correlation with the previous research of rub resistance estimated on digital UV prints on paper substrates with wheat straw pulp, where the amount of wheat straw pulp in the paper substrate had not significantly affected results [20]. Indeed, the type of ink was found to have a greater influence on the stability of the print during rubbing than the paper substrate itself [21].

Most prints, regardless of the paper substrates and printing techniques used, have colour difference values within the acceptable range (below ΔE_{00}* = 2), which means that the colour difference cannot be perceived by an untrained eye. By comparing the print stability in relation to the type of straw pulp added in recycled wood pulp during the production of the paper substrates and the number of rotation cycles in the rubbing test performed, it can be seen that the most stable prints within 20 rotations of rub resistance tests are obtained on paper substrates with 30 % of wheat straw pulp when using the flexographic technique (ΔE_{00}* = 0.38±0.09). The worst stability when simulating packaging handling (ΔE_{00}* = 1.39±0.33) is observed for offset prints on papers substrates with 30 % of triticale pulp (Fig. 2a). When observing the mechanical resistance within 40 rotations (Fig. 2b), the best results are obtained for flexographic prints on the paper substrate with 30 % barley (ΔE_{00}* = 0.78±0.21), but digital prints on the other substrates show similarly good results (ΔE_{00}* ranging from 0.75±0.30 to 0.99±0.33). The worst results are obtained for offset prints for all types of paper substrates with addition of cereal straw pulp (70N30W, 70N30B and 70N30TR) with ΔE_{00}* between 1.71±0.37 and 2.22±0.41, while the reference sample 100N showed the worst results with screen prints (ΔE_{00}* = 1.43±0.19).

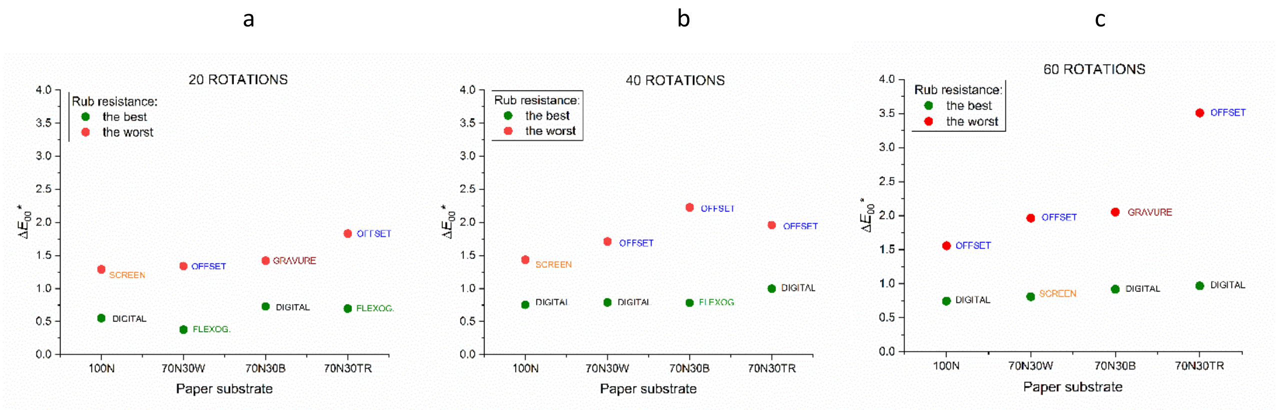
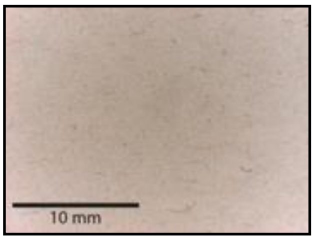
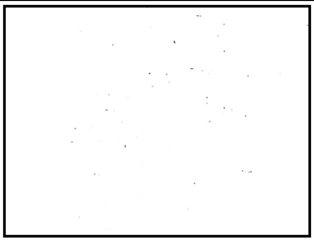
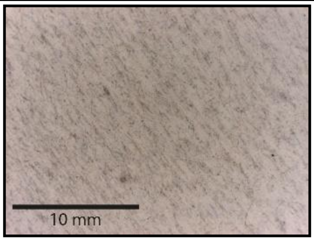
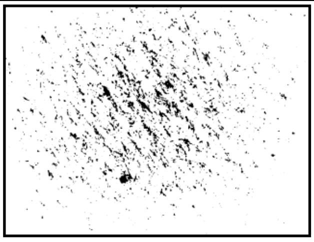
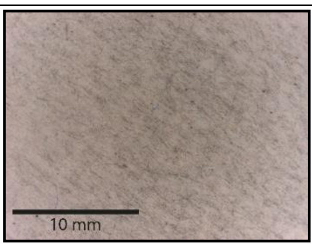
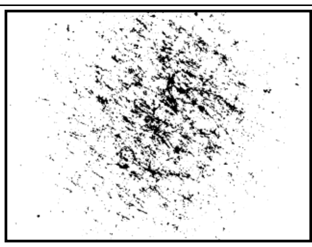
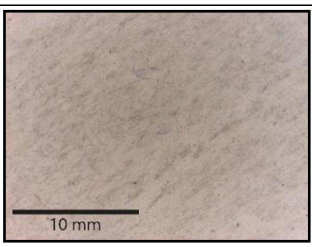
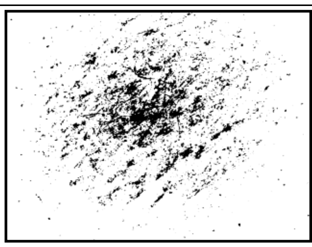
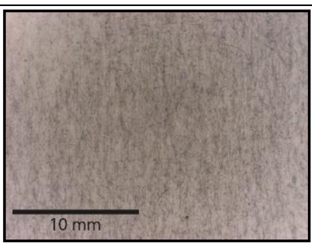
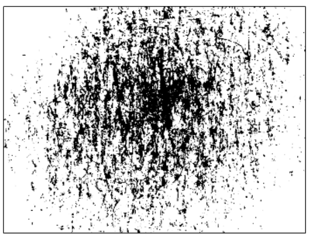


Figure 2. Comparison of the best and the worst colour differences ΔE_{00} for three rub resistance iterations: a) 20 rotations, b) 40 rotations and c) 60 rotations*

The best stability in the longest rub resistance test performed with 60 rotations (Fig. 2c) was shown for digital prints with similar results for the reference sample 100N (ΔE_{00}^* = 0.75±0.22) and papers with 30 % barley (ΔE_{00}^* = 0.92±0.32) or triticale straw pulp (ΔE_{00}^* = 0.97±0.27) as well as for screen prints on the paper substrate with added wheat straw pulp (ΔE_{00}^* = 0.81±0.21). The worst stability results, again, are determined for offset prints on most printing substrates (ΔE_{00}^* between 1.56±0.48 and 3.51±0.43).

Further examination of the worst evaluated prints after 60 rotations of the rubbing test was conducted by analysing the transferred ink from prints to the opposite uncoated recycled paper that served as the contact surface in the rubbing tests. First, a visual examination was performed on the microscopic images that recorded the transferred ink. Table 3 shows the original and analysed images of opposite paper surface (uncoated unprinted recycled paper) with the traces of ink from the prints after rubbing (60 cycles) and their percentages.

Table 3. Originally acquired and analysed images of the opposite uncoated recycled paper used as a receptor (a), and images and surface coverage by ink transferred after 60 rotations in the rubbing test for prints which showed the worst rub resistance 100N offset (b), 70N30W offset (c), 70N30B gravure (d) and 70N30TR offset (e)

	Original micrograph	Analysed micrograph	Surface coverage by transferred ink, %
a)			0.05
b)			5.02
c)			7.70
d)			8.84
e)			21.71

From the analysed image of the opposite paper surface (Table 3a) that was used as a receptor during rubbing tests, the area covered with ink was 0.05 %. This very small percentage could come from the ink remaining in the paper pulp during the recycling process. The lowest percentage of ink coverage (~5 %) was observed on the receptor surface after performed rubbing test of offset print on the paper 100N without the addition of straw pulp (Table 3b). Very similar coverage by the transferred ink (7.7 and 8.8 %) were observed on the surfaces of the receptor after the rubbing test of offset print on the paper 70N30W with 30 % wheat straw (Table 3c) and gravure print produced on the paper 70N30B with 30 % barley pulp (Table 3d). The highest percentage of ink transfer (21.7 %) was observed on the opposite paper surface after the rubbing test of offset printing on paper with 30 % triticale pulp (Table 3e).

Figure 3 shows the difference in the reflectance spectrum (ΔR) of the prints with the highest ΔE_{00}^* after 60 circular motions.

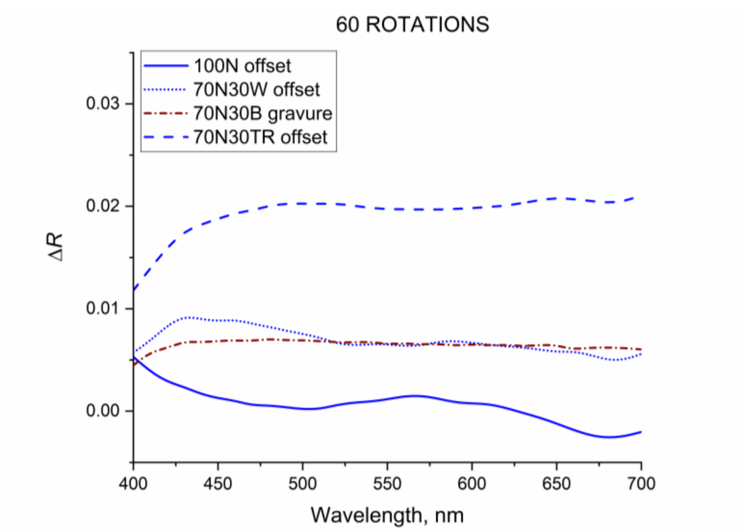


Figure 3. Differences in the reflection of the print (ΔR) which have shown the worst rub resistance after 60 rotations

In general, after performed rubbing test, the reflection of black prints increased slightly in the entire visible part of the spectrum. Namely, rubbing reduces the ink layer on the paper surface to a greater or lesser extent, causing light absorption to decrease and light reflection to increase. As a result of rubbing the print, the smallest difference in reflectance was observed for the printing substrate without straw pulp printed by the offset printing technique (100N). Very similar differences in reflectance were detected for offset print on the paper with 30 % wheat straw (70N30W) and gravure print on the paper with 30 % barley pulp (70N30B), while the highest difference in reflectance was observed after the rubbing test of offset print on the paper with 30 % triticale pulp (70N30TR). The obtained results additionally confirm the colour change shown in Figure 2c and calculated percentage of ink transfer to the receptor surface (Table 3).

4. CONCLUSION

By comparing the stability of UV-curable inks applied by different printing techniques on innovative paper substrates obtained by the addition of cereal straw pulp from wheat, barley, or triticale crops to reinforce pulp from recycled fibres, it can be concluded that digital prints are the most stable to rubbing based on the lowest colour differences even with prolonged rubbing treatment. Screen print had a slightly higher colour differences than digital prints, but again stability over longer rub cycles was good. Flexographic prints showed better stability under initial rubbing conditions simulating hand pressure and daily package handling (similar to digital prints) but deteriorated slightly under prolonged rubbing. The worst results were observed for the offset prints with the highest colour changes at the initial rubbing conditions, which can be compared to the colour changes of gravure prints. However, longer rubbing conditions showed greater colour differences indicating poorer acceptance of the ink on the paper substrate. Surface coverage by the transferred ink on the receptor surface (opposite uncoated recycled paper) after rubbing tests was in correlation with the difference in spectral reflectance. Offset prints on paper containing triticale straw pulp showed higher reflectance difference and greater ink transfer after rubbing test. Gravure prints on paper containing barley straw pulp and offset prints on paper containing wheat straw pulp showed similar reflectance difference and ink transfer. According to the conducted research, it is possible to conclude that all the examined prints have an acceptable quality and stability according to the tolerance standards of the printing industry. Since production of the paper substrates was carried out at the laboratory level, it is necessary to perform surface improvements such as smoothing or coating for offset printing with low-migration inks. These processes would significantly improve the adhesion of the ink to the paper surface, which is an area for further research.

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Otpornost na otiranje otisnutih inovativnih papirnatih podloga s pulpom slame žitarica

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Izvod

Papir je jedan od najvažnijih materijala za pakovanje i potražnja za njim je u stalnom porastu. Grafička industrija i industrija pakovanja neprestano istražuju alternativne izvore vlakana kako bi proizveli ekološki prihvatljiviji papir bez ugrožavanja kvaliteta. Papir kao ambalažni materijal mora ispunjavati visoke zahteve za čvrstoću, ali mora imati i prihvatljive površinske karakteristike kako bi se očuvao kvalitet štampe. Proizvodnja papirnih podloga od pulpe recikliranih vlakana ojačanih primarnim vlaknima slame žitarica te ocenjivanje kvaliteta štampe na takvim papirima dva su cilja ovog istraživanja. Pulpa za ovu svrhu dobivena je od slame tri žitarice: pšenice, ječma i pšenoraži. Otisci na papirnim podlogama dobijeni su primenom pet tehnika štampe. Stabilnost otisaka na trljanje je procenjena na osnovu izračunate razlike u boji i refleksiji od kolorimetrijskih vrednosti otisaka izmerenih pre i posle ispitivanja mehaničke otpornosti, te je načinjeno poređenje rezultata za predlog tehnike štampe koja će dati najstabilniji otisak na papirnim podlogama. Za otiske sa najvećom razlikom u boji u testu otiranja, površina receptora za test otiranja ispitana je na znake prenosa boje tokom testa, a površine pokrivenosti prenosa boje izračunate su na njihovim obrađenim mikrografijama.

Ključne reči: alternativni izvori vlakana; izdržljivost; proizvodnja papira; otiskivanje; UV-sušeća crna tinta