USABILITY AND PRINTABILITY OF PAPER SUBSTRATES WITH NON-WOOD FIBRES FOR GRAPHIC PRODUCTS PRINTED BY FIVE PRINTING PROCESS

UPORABLJIVOST I TISKOVNOST PAPIRNIH PODLOGA S NEDRVNIM VLAKNIMA ZA GRAFIČKE PROIZVODE TISKANE POMOĆU PET TISKARSKIH TEHNIKA

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Abstract
Customers are usually unaware of the process required to reproduce graphic products that are used on a daily basis. Manufacturers of graphic products and merchandise are aware that, regardless of the substrate they are printed, they must ensure consistent colour matching and print quality to attract attention on store shelves and ensure customer loyalty. Packaging, labels and publications are mostly printed using multicolour printing, whereby different colour shades are reproduced with the three standard process colours (cyan, magenta and yellow) in different ratios. The quality of the graphic product depends largely on the origin of the raw materials used for the printing substrate, the type of ink and the technology used for printing. The paper substrate most used for printing labels, packaging, or publications is generally made from cellulose fibres derived from wood, non-wood or non-plant sources. Nowadays, the use of non-wood lignocellulosic fibres resources plays an important role in optimizing raw materials for paper production. The aim of this research was to evaluate the usability and printability of paper substrates with the addition of non-wood fibres for graphic products printed by digital, flexographic, gravure, screen and offset printing process.

***Keywords**: non-wood fibre, paper substrate, printability, printing process, usability*

Sažetak
Kupci obično nisu svjesni procesa koji su potrebni za reprodukciju grafičkih proizvoda koji se koriste svakodnevno. Proizvođači robe i grafičkih proizvoda svjesni su da, bez obzira na vrstu tiskovne podloge, moraju osigurati dosljednu usklađenost boja i kvalitetu otiska kako bi privukli pozornost na policama trgovina i osigurali vjernost kupaca. Ambalaža, naljepnice i publikacije uglavnom se tiskaju višebojnim tiskom, pri čemu se različite nijanse boja reproduciraju s tri standardne procesne boje (cijan, magenta i žuta) definiranim u različitim omjerima. Kvaliteta grafičkog proizvoda uvelike ovisi o podrijetlu sirovina korištenih za tiskovnu podlogu, o vrsti boje i o samom procesu otiskivanja. Papirna podloga koja se najčešće koristi za ispis naljepnica, pakiranja ili publikacija obično se izrađuje od celuloznih vlakana dobivenih iz drvnih ili nedrvnih ili nebiljnih izvora. U današnje vrijeme korištenje resursa nedrvnih lignoceluloznih vlakana igra važnu ulogu u optimizaciji sirovina za proizvodnju papira. Cilj ovog istraživanja bio je ocijeniti uporabljivost i tiskovnost papirnatih podloga s dodatkom nedrvnih vlakana za grafičke proizvode otisnute digitalnim, fleksografskim, bakrotiskarskim, sitotiskom i ofsetnim postupkom tiska.

***Ključne riječi:** nedrvna vlakna, papirnata podloga, tiskovnost, tiskarski proces, uporabljivost*

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1. INTRODUCTION

Since paper substrates are traditionally made from lignocellulosic fibres derived from wood, the consumption of wood raw materials is increasing significantly every year, leading to a worldwide awareness of the reuse of waste paper as a source of cellulosic fibres [1, 2]. Since Matthias Koops founded the Neckinger factory in 1826 to produce white paper from printed waste paper, the recycling process has become a commercially popular technology. After several studies examining the effects of the recycling process on paper properties, it was found that the recycling process reduces the swelling capacity of the fibres and thus their flexibility [3]. In the last decade, the use of recycled paper in the paper and board industry has increased worldwide. Recycled paper accounts for about 50% of the total production of paper fibres used worldwide. The main purpose of recycled paper in Europe in 2010 was for the production of packaging with 63.7%, for publications with 26.0% (18.6% for newsprint and 7.4% for other graphic products), for household and sanitary purposes with 6.9%, and only 3.4% for other types of paper [4]. The use rates of recycled paper substrates vary greatly, depending on the desired quality and final purpose. Paper production cannot be based on recycled paper alone, as it cannot be used in all paper grades, nor can it be used an unlimited number of times [5]. Therefore, recycled fibres must be enriched with a certain amount of virgin fibres during paper production to increase the strength and quality of the paper [4]. Nowadays, consumers are increasingly demanding packaging that is environmentally and health-friendly with the aim of reducing, reusing and recycling the amount of waste worldwide [6]. Virgin cellulose fibres from agroresidues are a potential raw material for papermaking because straw offers many advantages as a fibre source: it is economical, abundant, and renewable [7]. Cereal straw is produced in large quantities annually in European countries in a significantly shorter growing cycle than wood [8]. The main objective of this research was to evaluate the usability and printability of paper substrates for a concrete graphic product, in which recycled wood fibres are enriched with virgin fibres from cereal straw. Laboratory-produced paper substrates with a straw fibre content of 30% from wheat, barley or triticale are printed using five of the most common printing techniques. To determine the breadth of usability of the graphic product with non-wood fibre, printing was done using digital technology (which is characterized by personalization printing), offset printing (which is mostly represented in publications and packaging), flexographic printing (which is mostly represented in packaging), gravure printing (which is characterized by high print quality, and therefore it is used for luxury products), and screen printing (which allows large ink applications on the printing substrates – and is used for decorative printing) [9-11]. In this paper, the assessment of the printability of paper substrates with agroresidues was considered based on the qualitative parameter trapping, which describes the ink acceptance, which is the basis for multicolour reproductions in the graphic industry.

1. MATERIALS AND METHODS

1.1. Production of laboratory paper substrates with non-wood pulp

The straw of three cereals: wheat (*Triticum spp.*), barley (*Hordeum vulgare L.*), and triticale (*Triticale sp*.), as agroresidue of the most abundant cereals in Croatia, was collected after harvest and manually cut into 3 cm long pieces with scissors. Purified straw was processed into semi-chemical pulp using the soda pulping process [5]. Laboratory paper substrates of about 42.5 g/m^2 were formed by Rapid-Kothen sheet former (FRANK-PTI) according to the standard EN ISO 5269-2:2004 [12], where straw pulp (wheat, barley or triticale) was added in proportions of 30% to the reference recycled paper pulp (Table 1).

According to their composition, four different laboratory papers were prepared. They were compared with each other and considered in relation to the paper made from recycled wood pulp.

Tab. 1: Laboratory paper substrates composition

MARK OF SUBSTRATE	COMPOSITION
N	100% recycled wood pulp - reference paper
30NW	30% wheat pulp + 70% recycled wood pulp
30NB	30% barley pulp + 70% recycled wood pulp
30NTR	30% triticale pulp + 70% recycled wood pulp

1.2. Printing of paper substrates with non-wood pulp evaluation of print quality

Today, several main printing techniques dominate in the graphic industry: offset printing, flexographic printing, gravure printing, screen printing, and digital printing. Each technique is better suited for a particular type of graphic product. Analog techniques produce high-quality prints based on the transfer of ink from the printing plate to the printing substrate, while digital printing uses inkjet or static transfer of ink directly to the printing substrate. Digital printing has revolutionized the printing industry, where inkjet printing, along with electrophotographic printing, is a rapidly growing digital printing technology. Inkjet printing is one of the most widely used non-impact printing techniques, in which ink is ejected directly onto the substrate by a nozzle device driven by an electronic signal [13]. Printing on the paper substrates produced in the laboratory was carried out according to the possible feasibility due to the small dimensions of the laboratory samples, where digital and screen printing were carried out in real production, while offset, flexographic printing and gravure printing were carried out at the laboratory level.

All samples were printed with ink on ink in full tone, so that the red (combination of magenta and yellow), green (combination of cyan and yellow), blue (combination of cyan and magenta) and brown (combination of cyan, magenta and yellow) colours were obtained on the prints. Depending on the printing technique, the prints were produced according to the recommendations of the ISO 12647 standard [14-18].

Digital printing was performed using EFI Rastek H652 UV curable inkjet printer with the resolution of 600 × 600 dots per inch (dpi) (respectively with high-quality mode 8 pass) and a printing speed of 12.10 m^2/h.

Offset printing was done on a Prüfbau multi-purpose testing machine with SunPak FSP (manufactured by Sun Chemicals) at a speed of 0.5 m/s and a pressure of 600 N.

Flexographic printing was done with an Esiproof laboratory device from RK Printcoat Instruments using Iroflex 917 (manufactured by Sun Chemicals) with anilox roller, total volume 39.1 cm^3/m^2 and engraved with a line screen of 40 lines/cm (screen angle 60 °).

Gravure printing was performed with Sunprop inks from Sun Chemical using a laboratory device KPP Gravure System with a printing cylinder of mechanical hardness (HS) 65 Shore and an engraved printing plate at an angle of 37 ° with a diamond needle at an angle of 130 ° with a screen of 40 lines/cm.

Screen printing of the samples was carried out on a semi-automatic machine from Shenzhen Juisun with Epta Hi-Gloss inks from KIIAN S.p.A. using a squeegee with a mechanical hardness of 75 Shore and a mesh size of 120 lin/cm. After printing, the prints were dried in the tunnel of the device NP -2413 (380V) manufactured by HIX corporation with warm air at a temperature of 55°C. All printing was performed at a temperature of 23 °C and a relative humidity of 50%.

1.3. Evaluation of usability and printability - analysis of the ink acceptance on the previously printed ink (trapping value)

One of the most important parameters affecting the quality of printing is the satisfactory absorption of ink on the already printed layer of ink. In order to obtain multicolour prints in the graphic industry, they are produced according to the subjective principle of colour mixing, where different tonal values are obtained on the print by printing full tone and/or halftone ink areas. A common method based on densitometric measurements to determine ink acceptability for previously applied ink is the Preucil method. According to this method, trapping values are measured on full tone areas (patches) on which two or three colours are printed on top of each other to produce a different shade:

magenta + yellow = red;

cyan + yellow = green;

cyan + magenta = blue;

cyan + magenta + yellow = brown.

The trapping values are calculated according to the following Equation 1.

$$AT = \frac{D_{op} - D_2}{D_1} x\ 100 \qquad (1)$$

where D_{op} is ink density of overprint, D_1 is ink density of previously printed ink or two inks and D_2 is ink density of last printed ink.

During the measurement, the ink density (D_i) was observed through the colour filter from the last printed ink using densitometer, eXact, X-Rite (D50/2°). It is desirable to obtain a high trapping value, close to 100%, which would mean a good acceptance of the ink on the previously printed ink or inks. The average values of all measured optical ink densities were calculated from 50 measurements.

2. RESULTS AND DISCUSSION

The reproduction quality, observed by the trapping value parameter, i.e., the acceptance of ink on ink, was carried out with the aim of determining the most suitable printing technique that enables satisfactory quality on printing substrates with the addition of cereal straw pulp. A recent study (Bates et al., 2022) has shown that digital ink penetration alone within the printing substrate has no direct influence on the acceptance of the ink on the printing ink [13]. To achieve the red, green, and blue colours on the prints, a combination of magenta and yellow ink, cyan and yellow ink, cyan and magenta ink, and cyan, magenta, and yellow ink, respectively, was used. All printing inks are printed in full tone to achieve the desired coloration. In all printing techniques used, the recommended sequence of inks was followed according to the standard ISO 12647 [14-18].

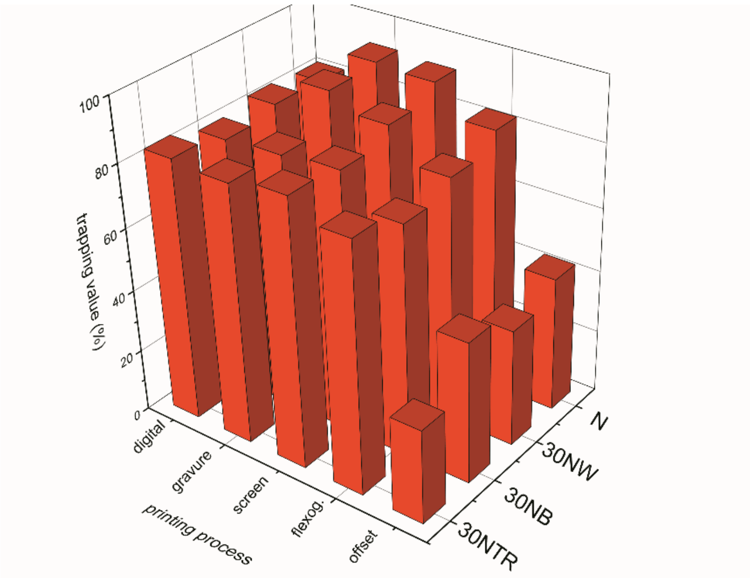

Fig. 1: Trapping values of red colour patch

From the results of trapping values presented in Figure 1, it can be seen that red offset prints contain the lowest trapping values, ranging from 30.14% (30NTR) to 43.17% (N), while with other printing processes similar results were achieved, ranging from 73.68% (flexograhic printing, 30NB) to 92.76% (gravure printing, N). The highest acceptance values of yellow ink on the previous printed magenta ink were obtained using the screen printing technique.

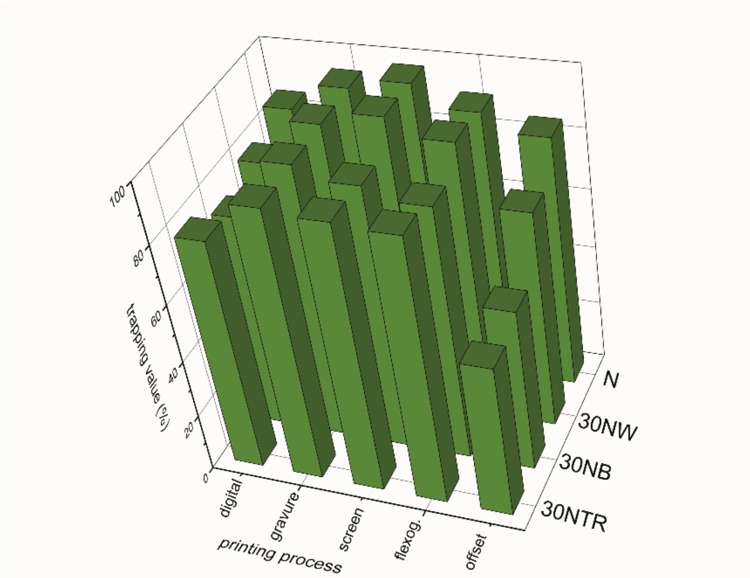

Fig. 2: Trapping values of green colour patch

In the case of green prints, a very similar trend was observed, except that the prints obtained by digital printing process showed a slightly lower trapping values compared to the red prints on the same paper substrates. From the trapping results on green prints (Figure 2), it is evident that offset prints again have lower values compared to prints obtained by other printing processes. Offset prints have trapping values ranging from 51.78% (30NTR) to 85.06% (N), while for prints with other printing processes values ranged from a minimum of 74.23% (digital printing, 30NB) to a maximum of 98.84% (screen printing, 30NW).

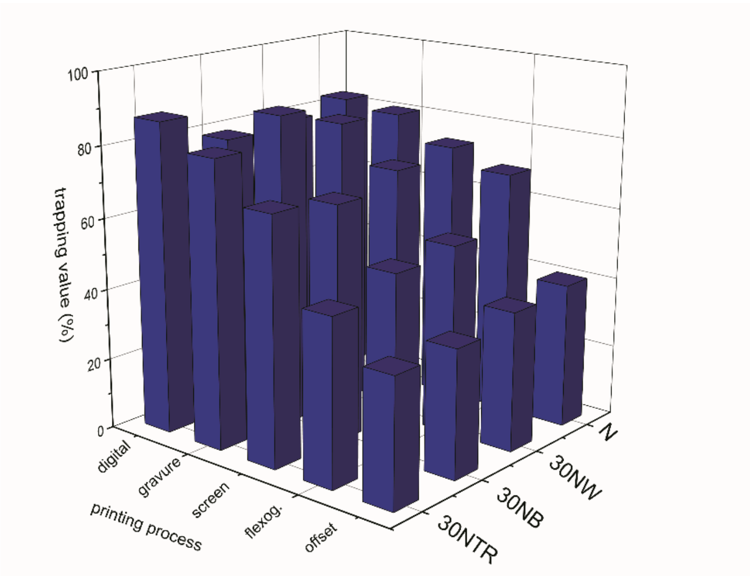

Fig. 3: Trapping values of blue colour patch

Similar behavior can be observed with the blue prints shown in Figure 3. The samples produced by offset printing process showed the lowest trapping values (35.82% - 40.73%), followed by prints produced by flexographic printing and other printing processes, which produced blue prints with very similar trapping values, ranging from 69.12% (screen printing, 30NTR) to 87.26% (digital printing, 30NTR).

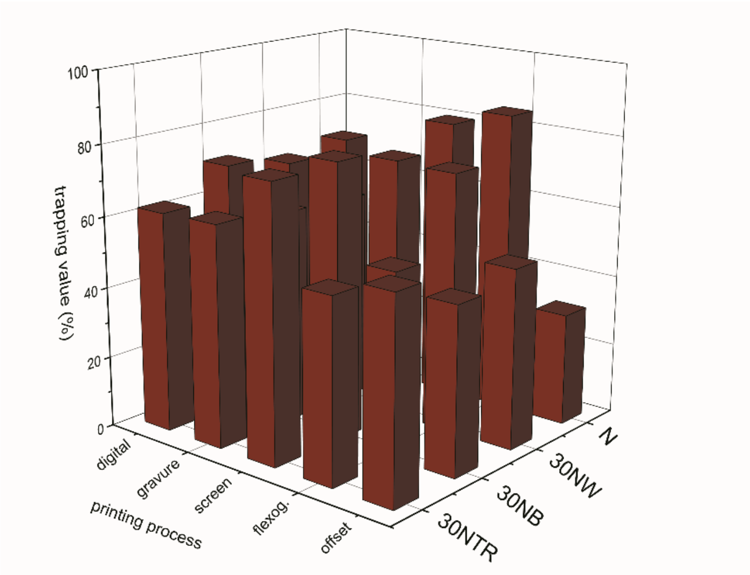

Fig. 4: Trapping values of brown colour patch

When reproducing the brown colour, which is achieved by printing with three process inks, one on top of each other, a reduction in the trapping value was observed in all prints (Figure 4). Again, offset prints have the lowest values (31.68% - 56.41%), followed by flexographic prints and gravure prints, then digital prints. Screen prints achieve the highest values of ink acceptance on ink ranging from 59.25 (30NB) to 84.99% (N).

On all analyzed multicolour prints, the highest trapping values were achieved on paper substrates printed with the screen printing technique, which is made possible by the printing process itself, whereby an ink layer of up to 12 μm is achieved (depending on the screen mesh size), while the thickness of the ink in offset printing is between 0.5 and 1.5 μm [9].

Comparing all prints obtained by different printing techniques, there is no significant difference between the printing substrates, regardless of whether they were made with recycled wood pulp only or with the addition of non-wood straw pulp.

3. CONCLUSION

Based on the results of the evaluation of usability and printability on paper substrates without non-wood pulp (N) and with an addition of 30% non-wood pulp: Wheat (30NW); Barley (30NB); Triticale (3N0TR), the following conclusions can be drawn:

◦ The highest trapping values, i.e., ink acceptance on previously printed ink, can be achieved with screen printing processes, up to 98.84% on 30NW substrate.

◦ Ink acceptance results on overprinted ink show reduced print quality when three inks are printed on top of each other to produce a brown colour for all printing techniques.

◦ For multicolour offset printing of substrates with the addition of 30% non-wood pulps, additional processing of the printing substrates is recommended to ensure higher reproduction quality, i.e., higher trapping values.

◦ All analyzed prints had high trapping values regardless of the printing technique used, which confirms the possible use of wheat, barley and triticale straw for the production of printing substrates for printed graphic products for all five printing process.

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