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TABLE OF CONTENTS

SECURITY MONITORING VIA SOUND ANALYSIS AND VOICE IDENTIFICATION WITH ARTIFICIAL INTELLIGENCE

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Abstract
The article demonstrates the possibility of monitoring user access through authentication based on voice profiles using the means of Artificial Intelligence. A two-stage approach is proposed for sound analysis and voice recognition using Feed-Forward Neural Networks (FFNNs) and Cascade-Forward Neural Networks (CFNNs). Seven test voice profiles were pre-processed to extract quantitative sound features. The procedure involves registration of a set of sound parameters concerning three categories, respectively, for all audio and acoustic measurements in the entire sound spectrum, measurements up to and above 100 dBA. The neural architectures were trained with Scaled Gradient Descent (SCG) and Levenberg Marquardt (LM) algorithms, using different transfer functions in the output structural layers. In the initial phase of neural training, the entire sound spectrum of registered indicators was used, and high levels of Accuracy around 90.0% were reached. Subsequently, steps were taken to reduce the informative features when searching for similar levels of accuracy in order to limit the necessary computational procedures in neural training, but maintain the threshold of successful user authentication. In the analysis of neural performance, in addition to accuracy, additional criteria were used, namely Mean-Squared Error (MSE) and Root Mean Squared Error (RMSE). About the achieved and analyzed results, a synthesis was conducted of a set of four informative features with the highest significance, respectively LAE (A-weighted, sound exposure level), Laeq (A-weighted, equivalent sound level), LAF (A-weighted, fast time-constant, sound level) and LAS (A-weighted, slow time constant response, sound level). In the course of subsequent neural training processes, unsuitability was found when using the Log-sigmoid activation type with greatly underestimated accuracy readings and errors below 58.0% and above thresholds of 0.2300 and 0.4800. Positive performance indicators of voice recognition were achieved with Softmax and Hyperbolic tangent sigmoid activations in SCG and LM training procedures in levels of accuracy of 98.7 % and 96.1 % at FFNN models. Successful correct recognition of the test voice profiles on access and security personalization with a quantitative

equivalent of 100.0 % accuracy was achieved in the Linear transfer function for Cascade-Forward Neural Networks. The proposed method and the synthesized neural models in the research can be used as units and modules in access control systems with biometric diagnostics and intelligent recognition of employees in company departments to electronically store classified information and physical access control.
Keywords: *security, personal authentication, voice profile, sound analysis, neural networks.*

Introduction

The main problems in voice recognition can be reduced to the interpretation and variation of the signals. Semantics, syntax, acoustics, and phonetics make speech difficult to process (Shaughnessy 2023). Recorded speech signals are often distorted by unwanted background noise, echo effects, and other phenomena. That is why the need for specially designed Automatic Speech Recognition (ASR) systems comes to the fore. The functionality of these systems is determined by the adaptation of three building mechanisms and the association of specific algorithms with them –P. Trivedi (2014); (Ivanko, Ryumin 2021); (Dudhejia, Shah 2018):

- Hidden Markov Model (HMM) - built on the basis of Forward, Viterbi and Forward-backward algorithms;
- Dynamic Time Warping (DTW): DTW has been used to compare different Speech patterns;
- Artificial Neural Networks (ANN): Three basic techniques are applied, as follows Supervised Learning; Un-Supervised Learning and Reinforced Learning. The most frequently indicated approaches are used in Feed-Forward, Recurrent, Long Short-Term Memory, and Convolutional Neural Networks.

The preprocessing process of speech signals regarding future extraction is implemented based on different approaches, mainly used in Frequency Domain. One of the effective tools in this direction is MFCC (Mel Frequency Cepstarl Coefficients). The approach is performed in the following step sequence: Preemphasis; Framing and Windowing; Fast Fourier Transform (FFT); Mel Filter Bank and Discrete Cosine Transform (DCT) - (Ivanko, Ryumin 2021); (Dudhejia, Shah 2018); (Sridhar, Kanhe 2023).

Due to the dynamics of the speech signals, empirical studies show that ASR performance often depends on the integration of hybrid modeling approaches, probabilistic estimations, coding and decoding procedures. Such a tool with maintaining high efficiency combines the advantages of DNN (deep learning principles) and HMM - (Sridhar, Kanhe 2023), (Yu, Deng 2015). In addition to the mentioned possibilities, the requirements for searching, adapting and creating innovative approaches regarding voice processing in Time Domain and application of neural devices other than classical ones are growing.

Methodology of the Research

The subject of the study is the development of a methodology for the synthesis of security authentication models and user access based on Sound Analysis (SA) and Artificial Intelligence (AI) Recognition. The proposed methodology was applied to individuals at different corporate levels, job positions and authorized privileges for physical access and information resources.

A series of experiments were conducted with different target groups differentiated by gender and age to confirm the reliability and effectiveness of the individual structural approaches to voice recognition. In the following sections, the procedures for one of the target groups of 7 persons in a mixed composition of male and female sexes are examined - respectively № 1, № 2, № 4 as woman profiles; № 3, № 5, № 6, № 7 as man profiles. The SA and AI authentication module integration goes through three implementation phases as follows:

- Voice Profile Registration and Processing for Future Extraction: During the first phase, the voice profile of each person in the Time Domain is registered and recorded. In parallel, speech sound processing is performed to extract 3 categories of Sound Parameters, respectively Group “Z” for all audio and acoustic measurements; Group “A” for measurements below 100 dB; Group “C” for sound levels above 100 dB. The procedure is repeated for a duration of about 15 seconds;
- Synthesis and Examine the Quality of Neural Models for Voice Profile Authentication: Parallel tests are conducted with the formed groups of sound indicators during processes of sequential training and verification of heterogeneous types of Artificial Neural Networks. These include Feed-Forward Neural Networks, Probabilistic Neural Networks and Cascade-Forward Neural Networks. The phase envisages the application of neural learning through Gradient Backpropagation Algorithms – Levenberg-Marqurdt, Scaled Conjugate Gradient, Conjugate Gradient with Powell/Beale Restarts, Fletcher-Powell Conjugate Gradient, Polak-Ribiere Conjugate Gradient, One Step Second and Variable Learning Rate Backpropagation, etc. “Softmax”, “Hyperbolic tangent sigmoid”, “Log-sigmoid”, “Linear” and other transfer functions can be used as neural activation in the structural layers. In the course of the conducted research, the highest success rate

compared to the intended target group and the introduced criteria "Classification Accuracy", "Mean-Squared Error", "Cross-Entropy", "Mean Absolute Error", "Root Mean Square Error (RMSE)" was achieved in the category of informative signs "A" - LAE, LAeq, LAF and LAS; FFNN and CFNN neural apparatuses with SCG and LM learning algorithms;

- Neural Models Functionality Investigation: The last phase of the research is devoted to a more detailed and in-depth analysis of the functionality of the selected neural models for voice authentication. Error evaluation procedures for Train, Validation and Test processes are implemented here; Gradient Train State; Classification and Misclassifications; Neural Sensitivity and Specificity; Error Variance.

Results and Discussion

- **Sound Analysis**

The behavior of the analytically obtained sound parameters when processing the empirical voice profiles can be analyzed on the oscillograms in Fig. 1, respectively LAE, [dBA]; LAeq, [dBA]; LAF, [dBA] and LAS, [dBA].

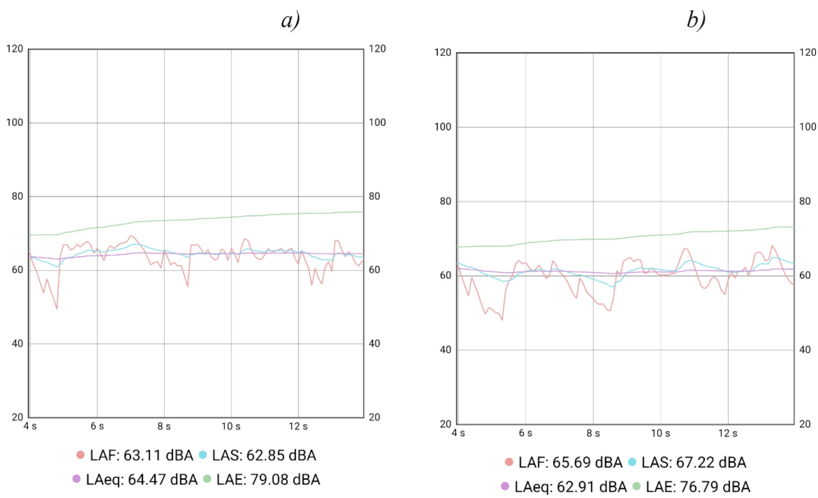


Fig 1. Levels of LAE, LAeq, LAF and LAS sound indicators for a) Person № 1 and b) Person № 7

A general trend is the approximately limited variation of LAeq and LAE sound parameters in all persons that are the object of recognition. While for the LAF and LAS indicators, relatively wider variations were observed compared to the individual phrases spoken in the range of the analyzed test voice profiles.

- **Synthesis Procedures**

Table 1 summarizes the results regarding the change of the “Cross-Entropy” and “Accuracy” criteria when gradually increasing the number of neurons in the hidden layers of the studied FFNNs in the output Softmax transfer function. The indicated indicators refer to SCG training algorithms with a variation of computational neurons in the second structural layer from 5 to 80, registered for voice samples from the test dataset. Cross-Entropy levels over “16.0000e-0” were found for neural structures containing 30, 50, 55, 60 and 80 hidden neurons with accuracies of 98.7 %, 97.0 %, 97.9 %, 98.6 % and 98.1 % obtained. In accordance with the optimality requirement “minimum error – maximum accuracy”, the FFNN was selected with the lowest Cross-Entropy index = 16.77750e-0 and the highest accuracy 98.7% among the listed 30 hidden neurons, shown in Fig. 2.a.

Table 1. Application of Feed-Forward models with SCG algorithm

Hidden neurons	Cross-entropy	Accuracy, %
5	10.23320e-0	75.4
10	10.91755e-0	91.9
15	13.06920e-0	94.2
20	10.77986e-0	90.4
25	11.54213e-0	90.8
30	16.77570e-0	98.7
35	12.21217e-0	94.1
40	13.70669e-0	93.7
45	15.38060e-0	96.0
50	16.98185e-0	97.0
55	16.81033e-0	97.9
60	17.04141e-0	98.6
65	12.15760e-0	95.2
70	17.03607e-0	98.2
75	12.60091e-0	94.4
80	16.98747e-0	98.1

Replacement of the learning approach SCG with LM and the type of neural activation in the output structural layers was performed with an identical change of the hidden neurons. In this regard, Table 2 contains a comparative quantitative analysis of the MSE, RMSE and Accuracy indicators between FFNNs with Log-sigmoid (Logsig) and Hyperbolic tangent sigmoid (Tansig) transfer function.

Table 2. Investigation of FFNNs with LM training algorithm at different output transfer functions

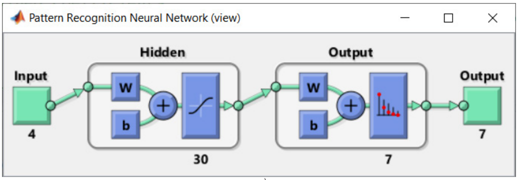
Hidden neurons	Logsig activation			Tansig activation		
	MSE	RMSE	Acc., %	MSE	RMSE	Acc., %
5	0.2446	0.4946	28.9	0.0469	0.2166	80.4
10	0.2410	0.4909	39.6	0.0167	0.1293	91.8
15	0.2437	0.4937	35.0	0.0126	0.1121	94.3
20	0.2429	0.4928	31.8	0.0146	0.1206	92.5
25	0.2405	0.4904	33.6	0.0229	0.1512	92.1
30	0.2440	0.4939	26.8	0.0138	0.1175	95.0
35	0.2444	0.4944	34.3	0.0155	0.1244	92.5
40	0.2412	0.4911	30.4	0.0147	0.1214	94.3
45	0.2427	0.4927	25.0	0.0222	0.1491	87.5
50	0.2379	0.4877	49.3	0.0183	0.1353	91.8
55	0.2347	0.4845	57.5	0.0254	0.1594	84.3
60	0.2403	0.4902	35.7	0.0125	0.1120	95.0
65	0.2409	0.4908	44.3	0.0275	0.1659	82.5
70	0.2447	0.4947	36.1	0.0295	0.1718	82.9
75	0.2395	0.4894	41.1	0.0097	0.0983	96.1
80	0.2371	0.4869	51.1	0.0194	0.1392	91.4

In the range of the first vs. the second used activation type, significantly increased MSE and RMSE as well as a lower degree of Accuracy were found in the output layers when manipulating the test voice profiles. Here, maximum MSE = 0.2447 and RMSE = 0.4947 are reached with a feed-forward network containing 70 hidden neurons. Minimum accuracies below the threshold of 30.0 % were obtained for models with 28.9 % in 5, 26.8 % for 30, 25.0 % for 45 hidden neurons. The highest achieved accuracy when using “Logsig” output activation falls in the range of only 57.5 % for FFNN at 55 structural neurons in hidden layer (Fig. 2.b). The advantage of the

“Tansig” transfer function is associated with the minimization of errors in times and a significant increase in the classification accuracy. Regarding the Mean-Squared Error, marginal minimum and maximum values of 0.0097 at 75 and 0.0469 at a set initial amount of intermediate computing units were found. A similar analogy was observed with the adopted second indicator for evaluating the quality of classification, where RMSE = 0.0983 and RMSE = 0.2166 were reported. Regarding the Accuracy criteria, the lowest levels below the threshold of 85.0 %, respectively 80.4 %, 82.5 % and 82.9 % were registered for neural structures with 5, 65 and 70 hidden neurons. The highest accuracy found for FFNN with “Tansig” determined with better adequacy compared to “Logsig” output activation equals 96.1 %, reached at 75 structural computation units, given in Fig. 2.c.

Table 3. Evaluation of Cascade-Forward Networks in LM algorithm

Hidden neurons	MSE	RMSE	Accuracy, %
5	0.0513	0.2266	80.7
10	0.0232	0.1522	89.3
15	0.0233	0.1527	92.5
20	0.0248	0.1576	90.4
25	0.0181	0.1347	94.3
30	0.0205	0.1430	93.6
35	0.0140	0.1184	96.1
40	0.0048	0.0692	100.0
45	0.0121	0.1099	96.4
50	0.0110	0.1051	97.9
55	0.0103	0.1017	98.2
60	0.0064	0.0801	99.3
65	0.0154	0.1242	96.8
70	0.0090	0.0947	98.2
75	0.0135	0.1163	97.1
80	0.0182	0.1348	96.8



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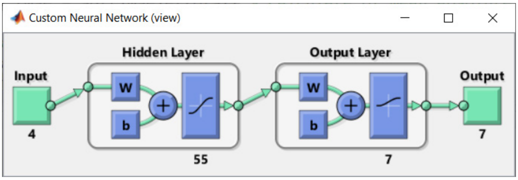

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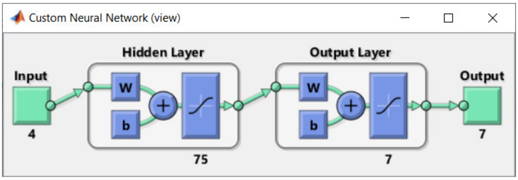

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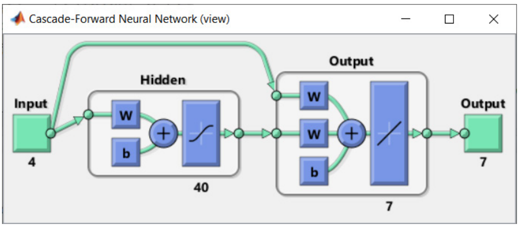


d)

Fig 2. Synthesized a) FFNN with SCG and Softmax, b) FFNN at LM and Logsig, c) FFNN in LM and Tansig and d) CFNN with LM for voice profile authentication

Table 3 contains the obtained equivalents of MSE, RMSE and Accuracy indicators in the performance estimation of Cascade-Forward Neural Networks. They represent a variety of FFNN with a characteristic feature of a direct connection between the input and each subsequent building layer, expressed in the inclusion of an additional Weigh matrix (w). CFFNs training procedures were carried out using the same approach as for the networks with “Log-sigmoid” and “Hyperbolic tangent sigmoid” functions, and here Linear activation was set in their outputs. As a result, an improvement of the quality indicators was achieved, as the levels of MSE and RMSE were reduced to 0.0048 and 0.0692, which were not registered until now. At the same time, full correct recognition of 100.0% of the voice samples at verification and test procedures was reached. The specified criteria were established for a network with the highest found degree of suitability with 40 hidden neurons in the structure presented in Fig. 2.d. The lowest accuracy of 80.7 % as well as the highest variations of MSE = 0.0513 and RMSE = 0.2266 were found for the CFNN model with a fixation of 5 neurons in the hidden layer.

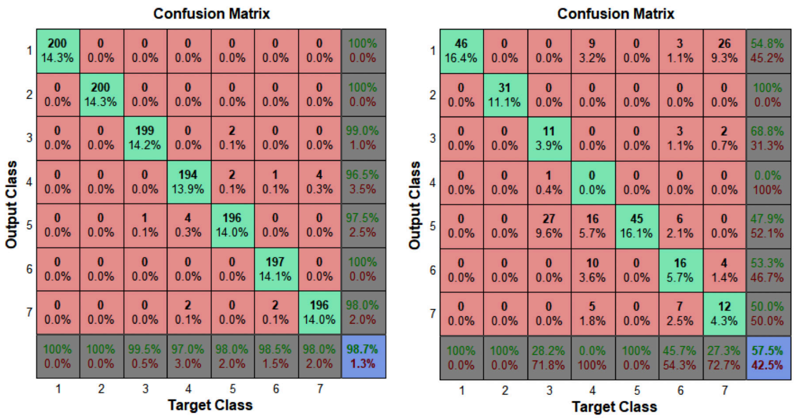
- **Functionality Assessment**

The analysis of the final models for voice management authorization is additionally supported by an assessment of:

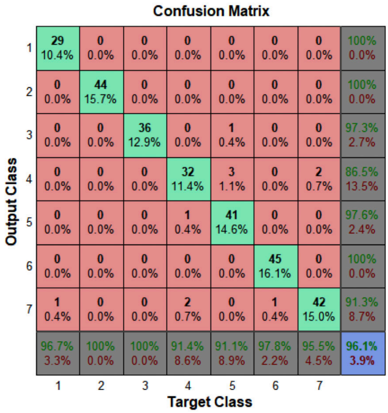
- the distribution of Classifications and Misclassifications in Fig. 3;
- Error variances for the data involved in the test subsets in Fig. 4.

In the direction from the first to the last matrix element diagonally, the standards with a correctly defined affiliation are located. The worst behavior is for the 3th, 4th, 6th and 7th test voice profile with FFNN with Log-sigmoid output transfer function, where the established Classification Sensitivities fall within the range of 28.2 %, 0.0 %, 45.7 % and 27.3 % (Fig. 3.b).

The low efficiency of the model is further confirmed by the increased range of variation of the network errors with strongly pronounced identical



a) *b)*



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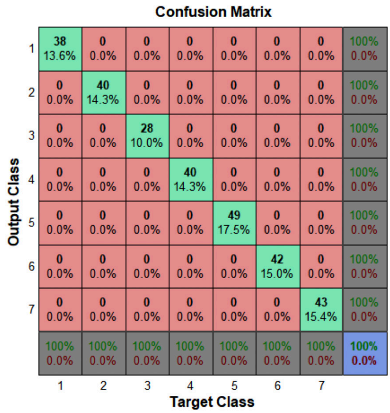
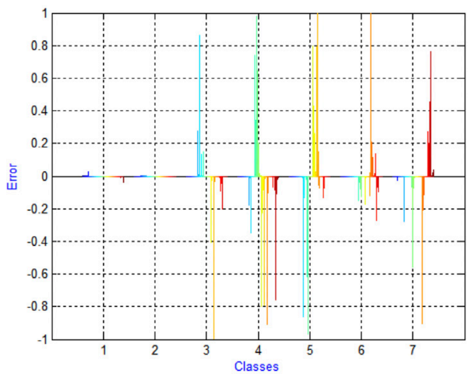


d)

Fig 3. Confusion matrices about a) FFNN in SCG and Softmax, b) FFNN with LM and Logsig, c) FFNN at LM and Tansig and d) CFNN with LM for person identification

peaks for large separate groups of test benchmarks falling within the limits –0.9285 to 0.5000, shown in Fig. 4.b. Despite the high accuracies of the individual classes – 3th, 4th, 5th, 6th and 7th voice profiles, for FFNN when using the SCG algorithm, significant minima and maxima of errors were observed in the interval –0.9960 to 0.99992, defining the model with particular and limited applicability (Fig 4. a).



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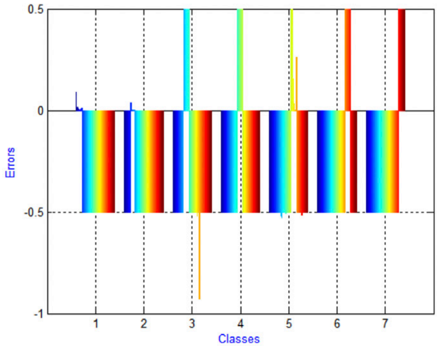

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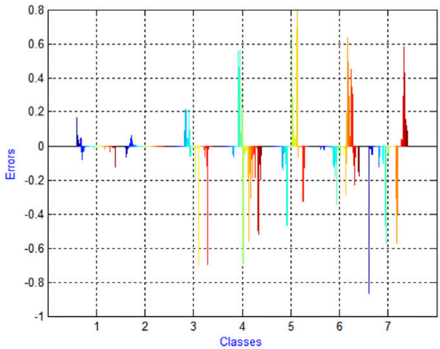

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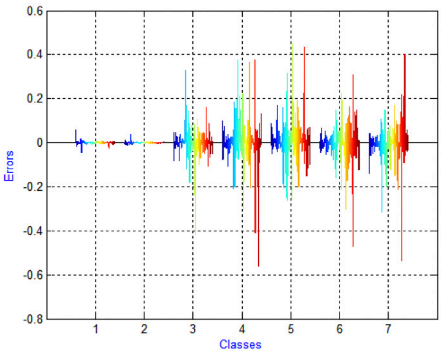

d)

Fig 4. Error diagrams for a) FFNN with SCG and Softmax, b) FFNN in LM and Logsig, c) FFNN with LM and Tansig and d) CFNN at LM in security personalization

Relatively lower compared to the previous ones, but still with reduced performance, are the observed variations in FFNN using LM learning method and Hyperbolic tangent sigmoid activation, respectively from -0.8668 to 0.7927 in Fig. 4.c. The narrowest range of network errors "-0.5599 to 0.4518" was reported for the selected CFNN model in Fig. 4.d – fact confirming the highest degree of adequacy for personalization of voice profile authentication processes.

Conclusions

The scope of the research allows to be expanded by including Machine Learning techniques such as Support Vector Machine, Discriminant Analysis, Naïve Bayes, CART and Boosted Decision Trees, k-Nearest Neighbor, etc. Additionally, modules for Spectral Analysis, feature acquisition and the study of the significance of individual components in the information samples in voice preprocessing procedures can be included. The reliability of the personal authentication activities should be improved by including Face Recognition and Fingerprint Biometrics. In this way, opportunities will be created for the construction and implementation of modular highly efficient Multimodal Biometric Systems at the industrial and corporate business level.

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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

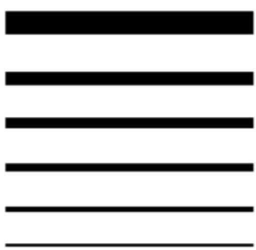
In order to achieve the same degree of whiteness as commercially bleached papers, the laboratory papers were coated with one or two layers. The TiO_2-based coating was applied separately in full-tone on laboratory papers using a digital UV LED piezo inkjet printing machine, a Roland VersaUV LEC-300. 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.

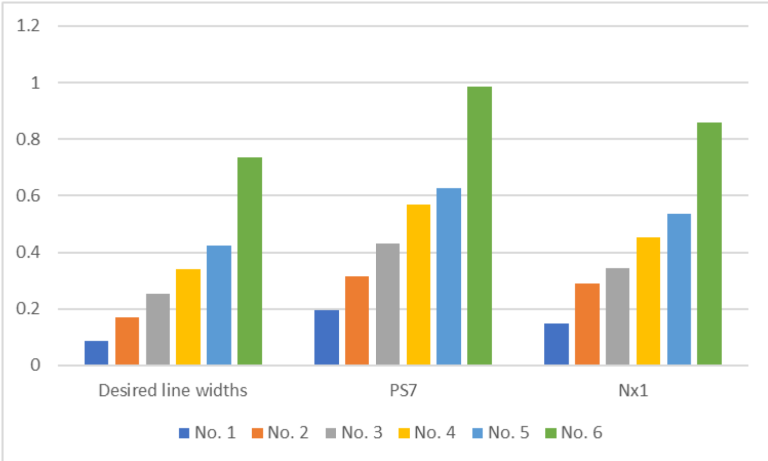
Table 3. The test pattern (desired line width and labels)

	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)

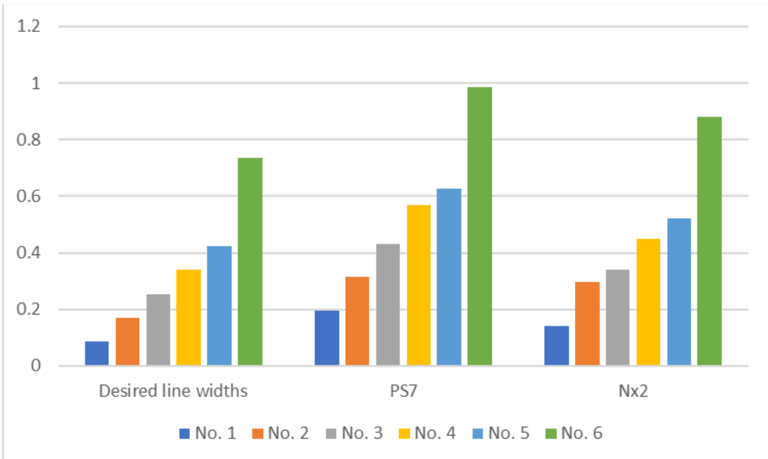


Figure 1. Line width on laboratory paper (in millimetres (mm)) made from 100% recycled wood pulp (N) coated with one layer of TiO_2 *(Nx1) and two layers of* TiO_2 *(Nx2) in comparison with the reference sample (PS7)*

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%

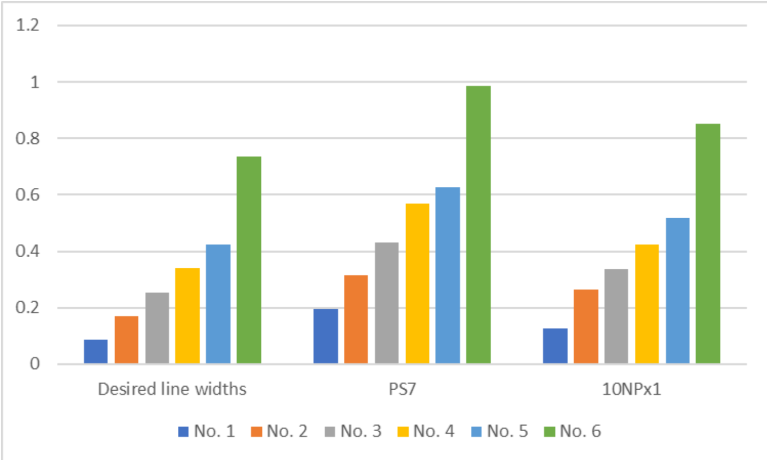
Table 5. Measured line widths printed on laboratory paper with wood pulp coated twice (Nx2), desired line widths and measured lines on reference paper PS7 and their differences

	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)

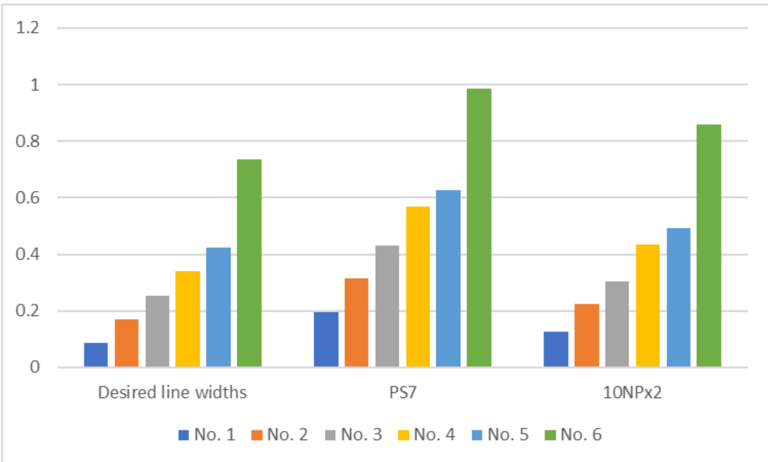


Figure 2. Line width on laboratory paper (in millimetres (mm)) made with 10% wheat pulp (10NP) coated with one layer of TiO_2 *(10NPx1) and two layers of* TiO_2 *(10NPx2) in comparison with the reference sample (PS7)*

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%

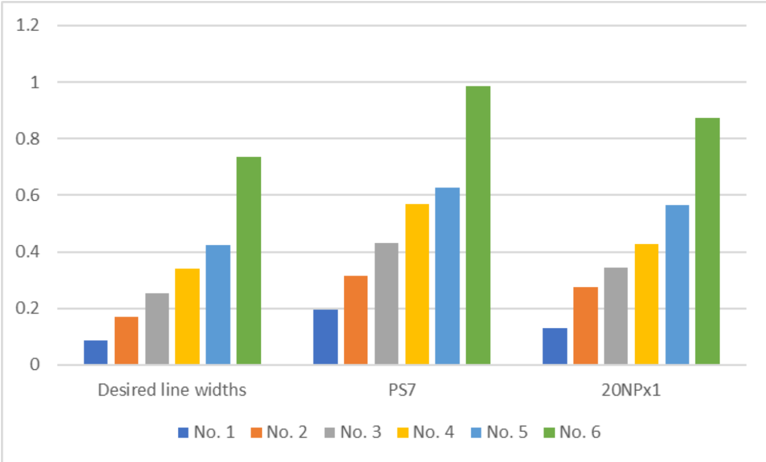
Table 7. Measured line widths printed on laboratory paper with 10% wheat pulp coated twice (10NPx2), desired line widths and measured lines on reference paper PS7 and their differences

	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)

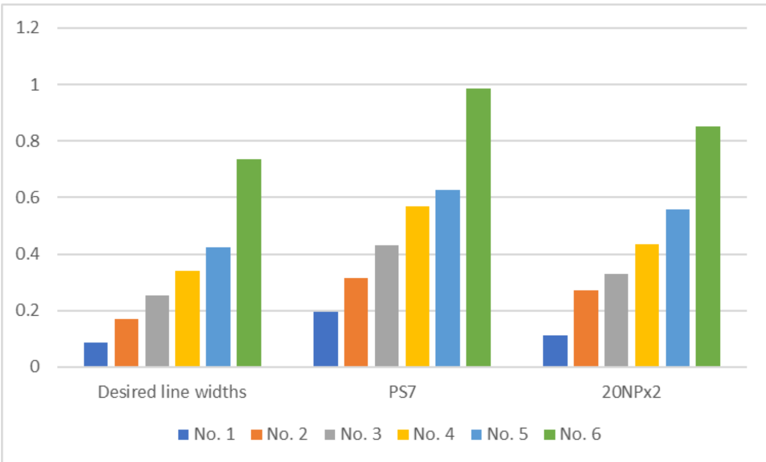


Figure 3. Line width on laboratory paper (in millimetres (mm)) made with 20% wheat pulp (2NP) coated with one layer of TiO_2 (20NPx1) and two layers of TiO_2 (20NPx2) in comparison with the reference sample (PS7)

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%

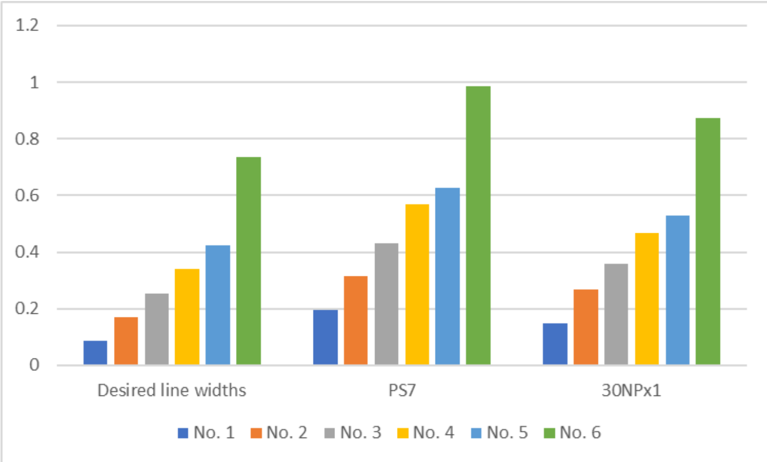
Table 9. Measured line widths printed on laboratory paper with 20% wheat pulp coated twice (20NPx2), desired line widths and measured lines on reference paper PS7 and their differences

	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)

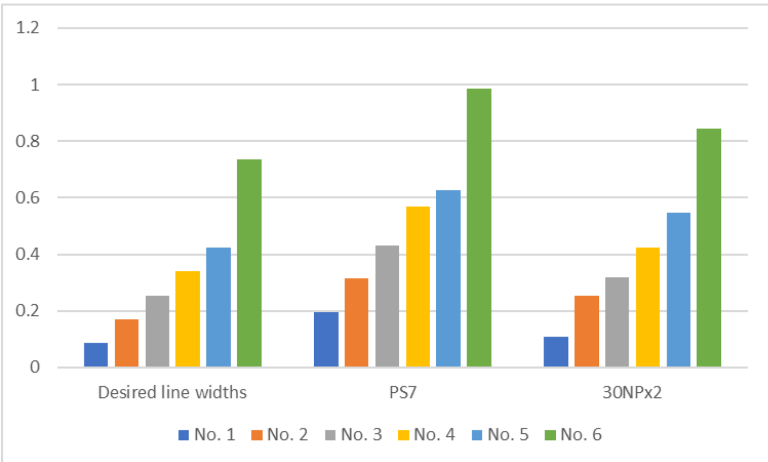


Figure 4. Line width on laboratory paper (in millimetres (mm)) made with 30% wheat pulp (3NP) coated with one layer of TiO_2 (30NPx1) and two layers of TiO_2 (30NPx2) in comparison with the reference sample (PS7)

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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BETTER REPRESENTATION OF THE LIMITS OF RGB AND CMYK COLOUR SPACES

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Abstract

Limits of RGB colour spaces are normally displayed as triangles in the CIE Yxy colour space. This type of diagram has the advantage that additive colour mixtures from two light sources actually all lie in a straight line. But CIE-Yxy colour space does not have uniform colour distances. So, a representation in other colour spaces with better equal spacing, such as CIE-Lab, shows better how good or bad the colour spaces really are.

Limits of an offset CMYK colour space were usually determined only at the six corners of the primary colours and the first-order mixed colours in CIE-Lab. It is much more meaningful to determine the limits of the most saturated colours in 10% increments.

The new visualisations were created using the Python library www.colour-science.org. The possibilities and limitations of this library will also be briefly explained.

Keywords: *sRGB, Adobe-RGB, PSOcoated_v3, CMYK, Colourspace-Borders, CIE-Yxy, CIE-Luv, CIE-Lab*

Introduction

In the daily work in the graphic arts industry, the conversion of colour spaces is often necessary and essential. In particular, the conversion of additive colour systems into subtractive colour systems is technically extremely demanding. These RGB colour spaces are commonly used according to their frequency of use in the graphics industry: Adobe RGB (see *Adobe RGB (1998) Color Image Encoding, 199 8, p. 9 ff.), sRGB (IEC-61966-2-1-1999-AMD1-2003.Pdf,* n.d.) and *CIE-RGB* (Vesely et al., 2019, p. 6). The expansion of the colour spaces is limited. If the limits of the RGB colour space used deviate too much from the limits of the CMYK colour space used for printing, software must offset greater colour deviations according to its algorithms. As software has not yet been able to perfectly reproduce human colour vision, major errors are to be expected. In day-to-day work, the aim should therefore be to use an RGB working colour space that deviates as little as possible from the subsequent CMYK output colour space. Fig. 1 shows the CIE standard colour space (Richter, 1996, p. 65 ff) and within it different RGB colour spaces. Similar representations are familiar to anyone who deals with colourimetry in any form. This type of diagram is often used to indicate how large the colour space is that is being enclosed.

Is it really enough to specify the colour space for offset printing using only six points, namely the three chromatic primary colours CMYK and the first-order mixed colours as shown in Fig. 4? In this study, all mixtures of a solid colour with another colour were determined in 10% increments. The results were processed with the Python library colour-science.org. There, the data for offset printing was simply converted from CIE-Lab to CIE-Yxy. The data was then displayed in the CIE-Yxy diagram using colour-science. In order to use the more equidistant CIE-Luv (*ISO/CIE 11664-5:2023,* n.d., pt. 5) and CIE-Lab (*ISO/CIE 11664-5:2023,* n.d., pt. 4), the usual RGB colour spaces had to be divided into smaller steps.

Methodology and equipment

Almost all the following graphics were created with an open-source library for Python. Python was used in the Anaconda environment (*Anaconda*, n.d.), both on Linux and PC, which in this case did not result in any changes. The name of the library for colour management is www.colour-science.org (*Colour Science for Python*, 2015). This library is very extensive and helpful. Its use would be a great relief for many researchers in the field of colour research. Unfortunately, it is not yet widely used.

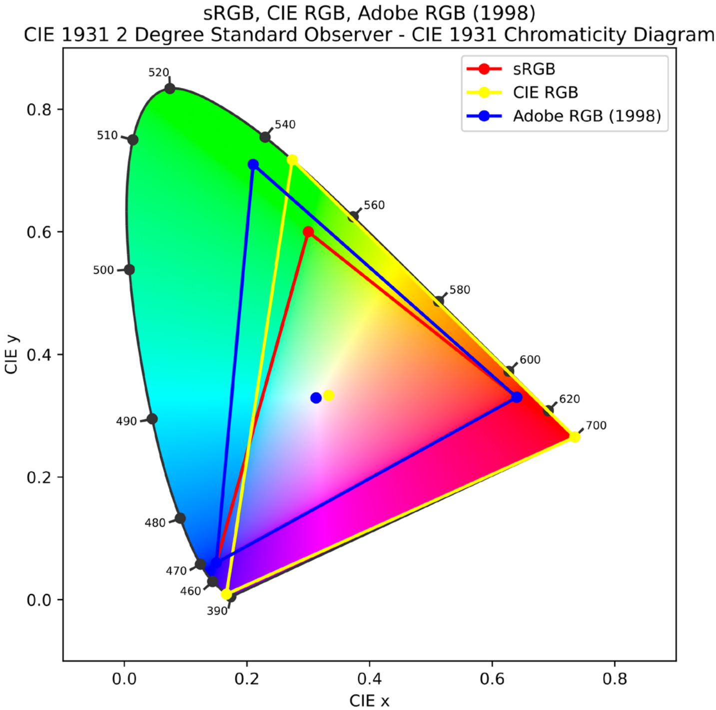

Fig 1. Color spaces in CIE-Yxy-Diagramm

Fig. 2 shows briefly how easy it is to create the diagram in Fig. 1 with colour-science. To generate these diagramms, various programme libraries have to be loaded. Then some definitions such as the used data format and the size are defined. Then the line width and the colours of the graphs are defined. The actual command is then completed in three lines. The programme code is still relatively simple. It gets more complicated later on.

```
plot_kwargs = [{"linewidth" : 2, "color": (1, 0, 0)},{"linewidth" : 2, "color": (1, 1, 0)},
    {"linewidth" : 2, "color": (0, 0, 1)}]
figure, colourspaces = colour.plotting.plot_RGB_colourspaces_in_chromaticity_diagram_CIE1931(
    ["sRGB", colour.models.RGB_COLOURSPACE_ADOBE_RGB1998,"CIE RGB"],
    plot_kwargs = plot_kwargs
    )
```

Fig 2. Code in colour-science.org for CIE-Yxy-Diagramm

The diagram Fig. 3 is similarly easy to create in Python. It shows the CIE-Yxy-Diagramm with the MacAdam ellipses. Each of the MacAdam ellipses shows an area within which a person with normal vision cannot distinguish colours. The Diagramm shows, that these ellipses have very different sizes. Colour distances in the diagram are never equally spaced. This, of course, raises the question: how useful is the first representation with the RGB colour spaces?

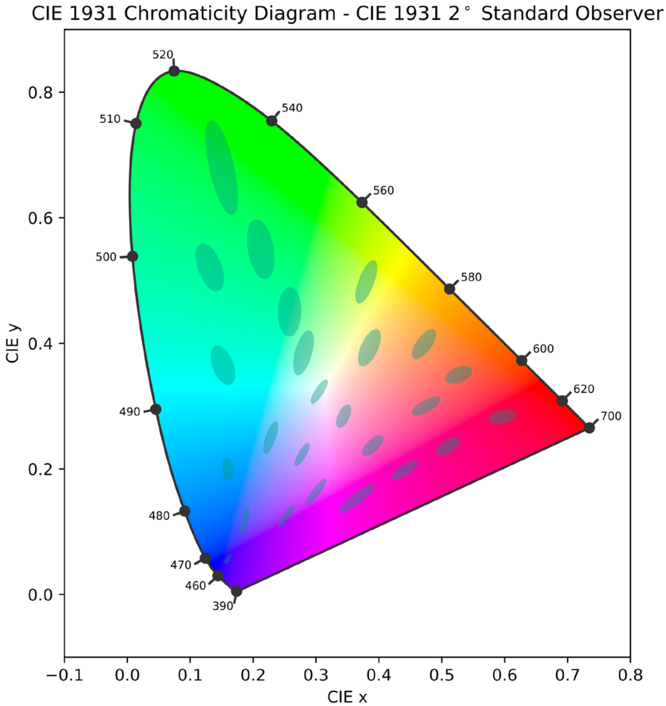

Fig 3. MacAdam-Ellipses in CIE-Yxy-Diagramm

In Fig 4, is entered a colour space for offset printing according to PSOcoatedV3 in the diagram, but only the pure CMYK primary colours and the first-order mixed colours. This representation can often be found on the Internet (López-Baldomero et al., 2022, p. 8). To obtain the colour values by converting the CMYK values into Lab values and from there into CIE Yxy values the Scribus colour management was used. In this CIE standard colour space, additive colour mixtures always run in a straight line from one light source to the next. This is why you can do the same with RGB colour spaces. Can this also be done with printing colours?

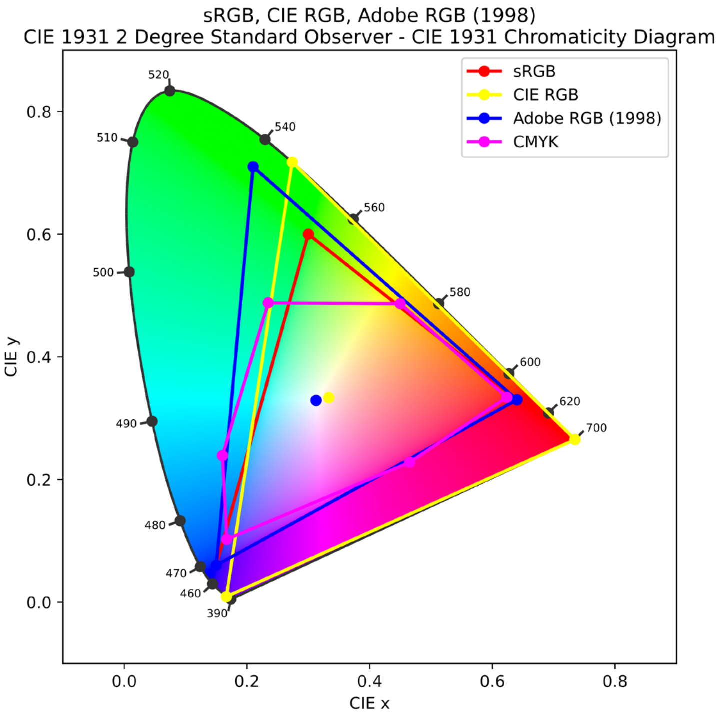

Fig 4. CIE-Yxy with RGB-Spaces and the usual representation of CMYK

Presentation of research results (Analysis)

In Fig 5. is shown why diagrams like Fig. 4 should not be used. The orange-coloured curve in the diagram shows the mixed colours, for example, 10% cyan and 100% yellow, 20 C and 100 Y, 30 C and 100 Y, also via the colour management of Scribus and colour-science in CIE-Yxy. The result is something similar to a triangle, but it is rounded and curved. It is particularly noticeable that there is also a corner in greenish yellow, which is completely missing if we only draw the graph through 6 points. This shows once again that it is not possible just to draw in subtractive colours and assume that the mixtures result in a straight line. The diagram shows that this is not the case. The colour space of offset printing inks should always specified by using more than 6 corner points. Every CIE-Yxy standard diagram in which subtractive colour mixtures are entered in only 6 points cannot be correct.

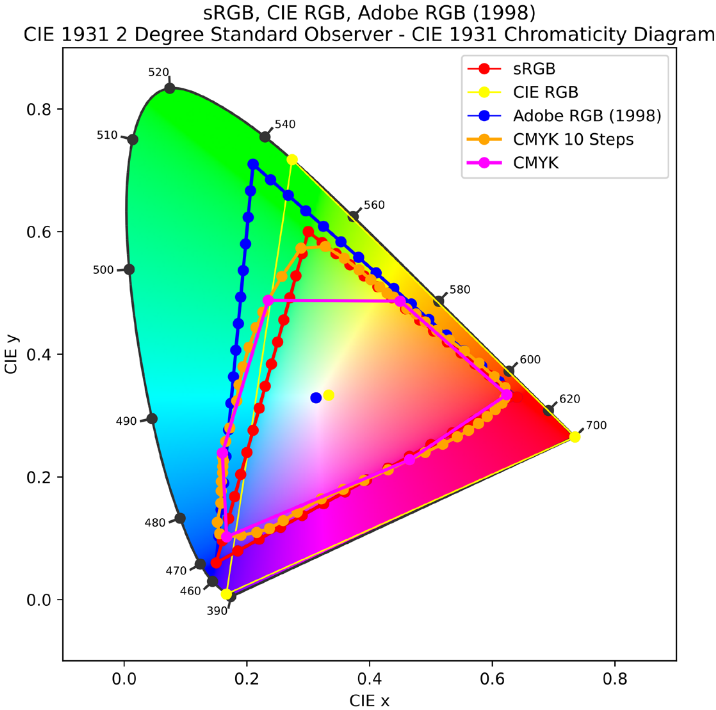

Fig 5. CIE-Yxy with RGB-Spaces, the real borders of CMYK according to PSOcoatedV3 and sRGB, Adobe RGB in more steps

In Fig. 6 another colour space is shown in which the MacAdam ellipses have a bit more uniform sizes than in the CIE-Yxy diagram, namely the CIE1976UCS diagram. UCS stands for Uniform Colour Space. This colour space is also known as CIE-Luv (*ISO/CIE 11664-5:2023*, n.d., pt. 5), as the axes of the diagram are labelled. For comparison purposes, in this Figure more interpolation points of the RGB colour spaces are calculated and as predicted these really do lie on a straight line. Unfortunately, this is often not explicitly mentioned in specialised literature.

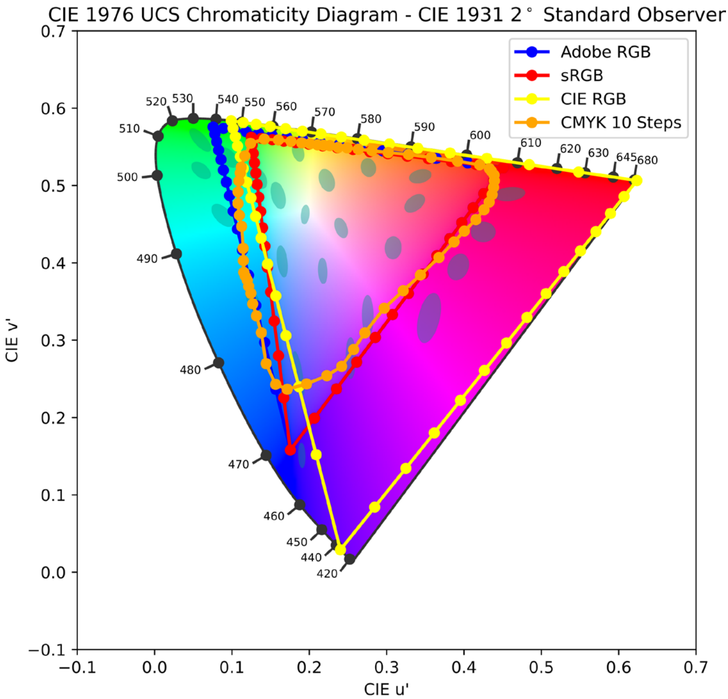

Fig 6. MacAdam-Ellipses, Adobe RGB, sRGB, CIE-RGB and CMYK according to PSOcoatedV3 in CIE-Luv-Diagramm

Furthermore, the diagram shows that sRGB and AdobeRGB differ less in this diagram than in CIE-Yxy. Why this CIE-Luv colour space, is used, which is rather uncommon in the graphic arts industry? The more common CIE-Lab colour space (*ISO/CIE 11664-5:2023,* n.d., pt. 4) is not available in this simple way at colour-science. This is not satisfying although there are convincing reasons for this. The colour space limits in CIE-Lab are dependent on brightness. They can only be cumbersome and calculated with the help of optimum colours. These colour space limits are usually called MacAdam limits (Martínez-Verdú et al., 2007). These Mac-Adam limits were calculated for different brightness levels in 1 % steps. Finally, all these MacAdam limits were then superimposed and calculated into a single graph, as shown in Fig.7.

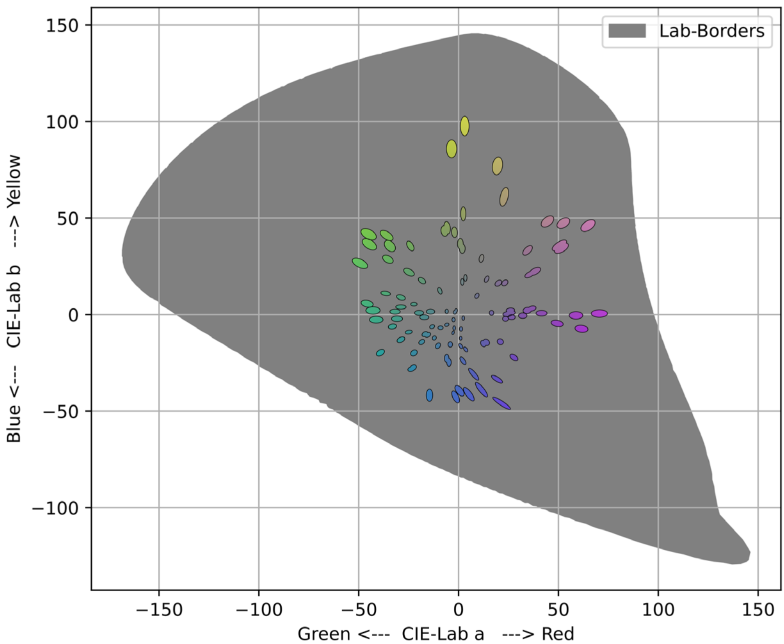

Fig 7. Summarised MacAdam limits with MacAdam ellipses according to Luo/Cui/Rig (2000)

Fig. 7 shows the boundaries of the Lab colour space and ellipses according to Luo, Cui and Rig from the year 2000 (Luo et al., 2001, p. 2). They also contain the MacAdam ellipses as well as those from other experiments. The RGB colour spaces can now be entered in these CIE-Lab colour space boundaries.

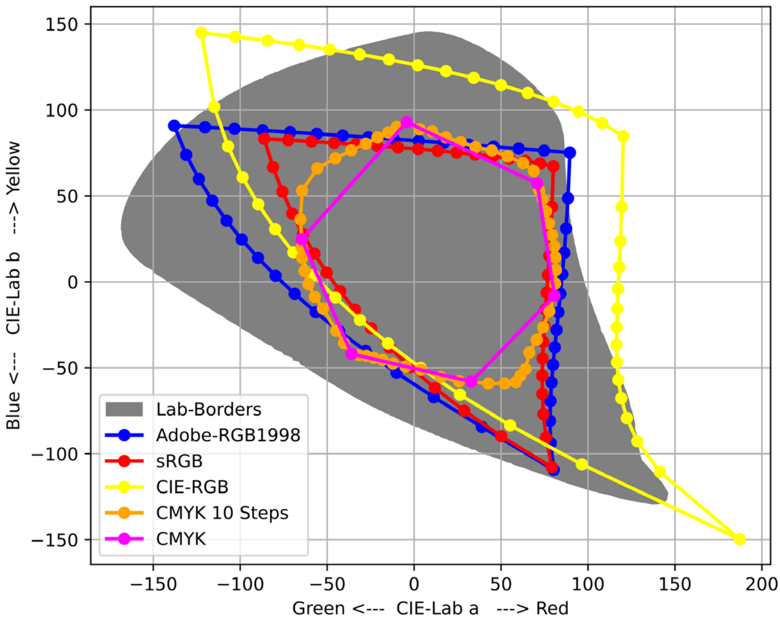

Fig 8. CIE-Lab with RGB-Spaces, the real borders of CMYK according to PSOcoatedV3 and sRGB, Adobe RGB in more steps

Fig. 8 shows the three RGB colour spaces examined and the CMYK colour spaces in the CIE Lab colour space. Firstly, it is remarkable that CIE-RGB sometimes goes far beyond the limits of CIE-Lab.The Lab colour space becomes less and less accurate the closer a colour is to the limits. In any case, further investigation is required to determine whether this is perhaps a software error of colour-science. Overall, however, it could also show that it is very easy to make any technical definitions. But just because it looks good in the first diagram does not necessarily mean that it is a good working definition in reality.

Secondly, it is worth noting that AdobeRGB actually almost completely encloses the offset printing colour space. Remarkably enough sRGB is not that much worse. The sRGB space even has the advantage that it allows far fewer colour definitions that cannot be realised in offset printing. This means fewer systematic errors in the colour space transformation. But this comes at the price of not being able to display a small range of the blue-green colours. Particularly the dark blue areas were expected to be particularly problematic. Apparently, this is not the case.

In office environments, most people work with PCs and Microsoft programmes. Adobe RGB is almost only used by graphics agencies or in the graphics industry. The vast majority of people therefore work with sRGB without realising it. So, most print shops therefore often also have to process files in sRGB. This usually works better than one would expect

```python
from matplotlib import pyplot as plt
import numpy as np

LabSpaces = plt
#LabSpaces = fig.figure(figsize=(7,7))
#LabSpaces = fig.add_axes([0,0,1,1])
LabSpaces.grid(True)

#LabSpaces.plot(LabBorders[1], LabBorders[2], label='Lab-Borders', linewidth = 2, c = 'grey')
LabSpaces.fill(LabBorders[1], LabBorders[2], facecolor='gray', edgecolor='gray', linewidth=1, label='Lab-Borders')

moresteps = colour.XYZ_to_Lab(colour.xyY_to_XYZ(more_steps_COLOURSPACE (15, colour.models.RGB_COLOURSPACE_ADOBE_RGB1998)))
LabSpaces.plot(moresteps[...,1], moresteps[...,2], label='Adobe-RGB1998', linewidth = 2, c = 'blue', marker = 'o')  # Plot some data on the axes.

moresteps = colour.XYZ_to_Lab(colour.xyY_to_XYZ(more_steps_COLOURSPACE (15, colour.models.RGB_COLOURSPACE_sRGB)))
LabSpaces.plot(moresteps[...,1], moresteps[...,2], label='sRGB', linewidth = 2, c = 'red', marker = 'o')  # Plot some data on the axes.

moresteps = colour.XYZ_to_Lab(colour.xyY_to_XYZ(more_steps_COLOURSPACE (15, colour.models.RGB_COLOURSPACE_CIE_RGB)))
LabSpaces.plot(moresteps[...,1], moresteps[...,2], label='CIE-RGB', linewidth = 2, c = 'yellow', marker = 'o')  # Plot some data on the axes.

LabSpaces.plot(CMYKborders60Lab[...,1], CMYKborders60Lab[...,2], label='CMYK 10 Steps', linewidth = 2, c = 'orange', marker = 'o')
LabSpaces.plot(CMYKbordersMiniLab[...,1], CMYKbordersMiniLab[...,2], label='CMYK', linewidth = 2, c = 'magenta', marker = 'o')
LabSpaces.legend(loc='best')
LabSpaces.xlabel('Green <---  CIE-Lab a   ---> Red')
LabSpaces.ylabel('Blue <---   CIE-Lab b   ---> Yellow')

LabSpaces.show()
```

Fig 9. Most parts of the python-code

Fig. 9 shows the essential parts of the source code for Fig 8, the diagram before. In the shown code 15 steps in each case are defined. The whole definition of the boundaries of the CIE Lab colour space is missing, the input of the data for the offset printing colour space is missing and the function more_steps_COLOURSPACE, which divides the straight lines of the RGB colour spaces into several parts. However, the data for the offset colour spaces, the limits of the Lab colour space and the code for the missing functions can be requested from the author.

Conclusions

1. Colour space of offset printing inks must be drawn in diagrams using more than 6 corner points.
2. In CIE-Luv colour space the additive mixtures of two colours also lie on a straight line like in CIE-Yxy.
3. CIE-RGB has wide ranges that cannot be displayed at all in CIE-Lab and are therefore probably not perceptible.
4. Using the sRGB colour space instead of the Adobe RGB colour space should not have too many disadvantages. Only colours of the very saturated light greenish blue could be displayed a little less saturated.

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A SYSTEMATIC APPROACH TO THE QUALITY ASSESSMENT OF PRINTED PRODUCTS

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Abstract
Quality standards for the technological processes of the production of finished products are used in all countries of the world. Consumers of printing and packaging products are increasingly demanding ISO 9001 quality system certificates from manufacturing companies. It should be noted that international and national standards use different approaches to the standardization of processes and products, and the content of project management. To meet the demands of consumers, which are constantly increasing, quality management should be carried out based on a set of scientifically based principles, which can be divided into system-wide and special. The problem is relevant for modern Ukrainian enterprises, where, on the one hand, they need serious changes in the organizational structure, corporate culture, style and methods of project management; and on the other hand, compliance with the ratio of responsibility for quality between the management system and performers.
Evaluation of the quality of printed products at the current stage requires the application of the principles of a systematic approach, based on the principles of which it is possible to build a coherent, logically completed methodological system of quality indicators of a specific type of product. This will also make it possible to justify the problem of choosing certain methods and will give a normative and regulatory character to those indicators that are not reflected in the standards but are important for the practical use of products.
To create one or another model of the system, it is first necessary to carry out its verbal and informational description and tuple recording. The components of a verbal informational description usually reflect a description of the external environment, and the system's connections with it; identification of the relationship between factors, characteristics of the variability of factors; elementary composition of the system, and its parts; description of connections between elements of the system and subsystems; operation of the system, i.e. description of the process of functioning and development of the system. The tuple record of the system model of the quality

assessment takes into account the classification characteristics of products, the set of "inputs" and "outputs" of the system; a set of variable parameters and processes.
The goals of quality management at each stage of the technological process for each specific type of printed product can be individual. To cover the management of all stages of the life cycle of media or packaging products within the subsystems of the quality system, it is necessary to perform a full set of special (specific) quality management functions. The matrix method or elements of the ISO 9000 series system can be used to form these functions.
Keywords: *systematic approach, quality, printed products, standard.*

Introduction

Evaluation of the quality of printed products at the current stage requires the application of the principles of a systematic approach, which is oriented towards the study and knowledge of the entire set of complex hierarchical relationships between them. Such a methodological approach to the methods of evaluating the qualitative indicators of printed products and their classification makes it possible to identify ways of their systematization. Based on the principles of system analysis, it is possible to build a coherent, logically completed methodological system of quality indicators of a specific type of product. This will also make it possible to justify the problem of choosing certain methods and give a normative and regulatory character to those indicators that are not reflected in the standards but are important for the practical use of products. To create one or another model of the system, it is first necessary to carry out its verbal and informational description and tuple recording. The components of a verbal-informational description usually reflect a description of the external environment, the system's connections with it; identification of the relationship between factors, characteristics of the variability of factors; elementary composition of the system, its parts; description of connections between elements of the system and subsystems; operation of the system, i.e. description of the process of functioning and development of the system.

Ukrainian and foreign scientists obtained important results in the research of the problem of assessment and quality assurance of printed products: V. Senkivskyi (2012), I. Pikh (2017), A. Kudryashova (2022), G. Kipphan (2001), D. Sajek (2022), A. Windriya (2020) et al.

At the same time, the analysis of literary sources showed a lack of research aimed at identifying multiple factors and determining the importance of their influence on the implementation of the processes of forming, printing and finishing printed products, determining optimal alternative options for the implementation of these processes, and comprehensive prognostic assessment of quality.

Therefore, the research of the technology of predictive assessment of the quality of various types of printed products and packaging based on system analysis and fuzzy logic tools is an urgent task.

Methodology and equipment

To create functional models of preprint, print, and post-print processes, the system and matrix analysis were used. The principles of the theory of hierarchical multi-level systems were used to isolate and formalize the relationship between factors influencing the quality of printed products and to create models of the priority influence of factors on the analyzed technological processes. To optimize the weight values of factors and synthesize models of their priority influence, methods of pairwise comparisons and multifactorial selection of alternatives based on the linear collapse of criteria, methods and tools of fuzzy logic were used. Fuzzy logic makes it possible to perform fuzzification, which consists of replacing the concepts of a clear set with the concepts of a fuzzy set, that is, comparing the set of values of its belonging functions. It is advisable to use this approach in the study of technological processes, the factors of which cannot be presented in numerical form. Accordingly, a comparison of term-sets of values of the analysed factors and belonging functions necessary for their formalization is carried out. Fuzzification provides a high level of correspondence of the model to the real state.

Analytical research and problem solutions

When developing a method of forecasting the quality of printed products with the use of fuzzy logic, several scientific and methodological principles are applied: the linguistic nature of the forecast (output) and input factors; linguistic knowledge; hierarchies of the knowledge base (figure 1) (S. Havenko, Hileta et al., 2019).

A hierarchical structure of the mathematical model was built based on the formalization of the influence factors given by fuzzy sets. Belonging functions were used to estimate and optimize the values of formalized linguistic factors. The study of the process of evaluating the quality of printed products consists not only in the ranking of factors. An important problem is the numerical expression of the degree of influence of a factor of a lower level on an element of a higher level associated with it, or the degree of dominance of a factor. It is called numerical or cardinal agreement according to the level of priority (Stetsenko, 2010; Tomashevskyi, 2005).

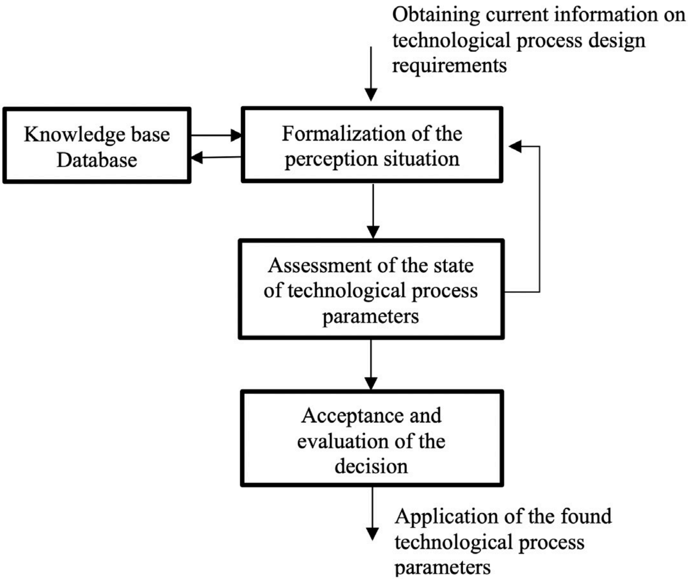

Fig 1. Structural diagram of the process of assessing the quality of perception

A set of determining factors affecting the process of design and production of printed products was identified as a result of the analysis of literary sources (S. Havenko, 2002; Havrysh & Tymchenko, 2014; M. Havenko, 2016) and expert survey.

Research results

It is important to build a quality model of the print production process. Let's consider the process of realization of the stages of the creation of printed products as a function $Q= F (p_1 \quad p_2\ p_3)$, whose arguments are factors (linguistic variables) and p_1, p_2, p_3 – weights for factors. The value of this function will determine the predicted integral indicator of the quality of the implementation of the production process Q, expressed through partial indicators of the quality of linguistic variables, grouped according to their functional purpose.

$$Q = F (X\ Y\ Z\ T) \quad (1)$$

Argument X identifies an indicator that determines product quality: $Y = F_y (y_1, y_2, y_3)$, where y_1 is the linguistic variable "preprint"; y_2 is the linguistic variable "print"; y_3 is a linguistic variable "post-print". The Z argument identifies a total indicator that determines the quality of product processing. The T argument identifies a total indicator that determines the quality of the marketing data.

Let's design a fuzzy knowledge base and define an integral indicator of the quality of the product manufacturing process. To do this, let's establish the linguistic terms of the integral indicator. Let the integral indicator be the linguistic variable Q — "the quality of the implementation of product manufacturing processes", and the linguistic terms of this variable will be the terms "low", "medium", and "high".

At the next level, we refer the terms "low", "medium", "high" to the following linguistic variables:

C — "quality of preprint processes",

V — "quality of print processes"

G — "quality of post-print processes."

The fuzzy knowledge base, according to the multi-level model of fuzzy logic derivation, which reflects the hierarchy of linguistic variables, will have the form:

IF (C= low) I (C= medium) I (C= high)

I (V= low) I (V= medium) I (V= high)

I (G= low) I (G= medium) I (G= high),

THEN (Q= low) I (Q= medium) I (Q= high).

Based on the established conditions, let's build a matrix of knowledge (Table 1).

Table 1. Knowledge matrix for the linguistic variable Q

Quality of products output data (preprint)	Quality of print processes	Quality of post-print processes	Quality of the set of production processes
C	V	G	
low	medium	low	low
medium	low	low	low
medium	medium	low	medium
high	medium	medium	medium
high	high	high	high
high	medium	high	high

The knowledge matrix for the linguistic variable Q will correspond to fuzzy logic equations. Belonging functions will have the form:

for the term «low»
$\mu_{low}(Q)= \mu_{low}(C)\wedge\mu_{medium}(V)\vee\mu_{low}(G)\wedge\mu_{medium}(C)\vee\mu_{low}(V)\wedge\mu_{low}(G)$

for the term "medium"
$\mu_{medium}(Q)=\mu_{medium}(C)\wedge\mu_{medium}(V) \wedge \mu_{low}(G)\vee\mu_{low}(C)\wedge\mu_{medium}(V)\wedge\mu_{medium}(G)$

for the term "high"
$\mu_{high}(Q)=\mu_{high}(C)\wedge\mu_{high}(V)\wedge\mu_{high}(G)\vee\mu_{high}(C)\wedge\mu_{medium}(V)\wedge\mu_{high}(G)$

The generalized version of the logical statement for the linguistic variable "preprint quality" will have the form: IF (C_1) = (small, medium, high), (C_2) = (simple, complicated, complex), (C_3) = (small, medium, high), THEN (C) = (low, medium, high). The general fuzzy set of the linguistic variable Q for the analysed belonging functions concerning the fuzzy terms "low", "medium", and "high" and the corresponding values of the variable Q will have the form:

$$Q (C,V,G)= \{\mu_{low}(Q)/k_1, \mu_{medium}(Q)/k_2, \mu_{high}(Q)/k_3\} \qquad (2)$$

where k_1, k_2, k_3 — quantitative values of the variable Q concerning the analysed terms. The next stage of research is defuzzification. To implement this stage, we build a table based on term-sets with normalized values of belonging functions at three points of division of the universal set of values D of each linguistic variable.

Table 1. Term-set belonging functions

	K (g_1)(preprint)			K (g_2)(print),			K (g_3)(postprint)		
D_1 (conventional units)	1	2	3	1	2	3	1	2	3
$\mu_{low}(d_1)$	0.11	0.25	1	0.17	0.2	1	0.11	0.14	1
$\mu_{medium}(d_2)$	1	0.14	1	1	0.11	1	1	0.12	1
$\mu_{high}(d_3)$	1	0.17	0.11	1	0.2	0.11	1	0.2	0.13

Let's substitute the values of the terms "low", "medium", "high" from Table 2 into fuzzy logic equations for the linguistic variable C:

for the term “low”

$\mu_{low}(C)=12 \wedge 0.17 \wedge 0.25 \vee 0.17 \wedge 0.25=0.17$

— for the term “medium”

$\mu_{medium}(C) =0.12 \wedge 0.14 \wedge 0.25 \vee 0.12 \wedge 0.14 \wedge 0.11=0.12$

— for the term “high”

$\mu_{high}(C)=0.2 \wedge 0.25 \wedge 0.2 \vee 0.12 \wedge 0.14 \wedge 0.2=0.2$

Let’s substitute the values of the terms “low”, “medium”, “high” from Table 2 into fuzzy logic equations for the linguistic variable V:

— for the term “low”

$\mu_{low}(V)=0.2 \wedge 0.17 \vee 0.11 \wedge 0.17=0.17$

— for the term “medium”

$\mu_{medium}(V) =0.2 \wedge 0.14 \vee 0.11 \wedge 0.14 \wedge 0.14=0.14$

— for the term “high”

$\mu_{high}(V)=0.2 \wedge 0.25 \vee 0.11 \wedge 0.25=0.2$

Let’s substitute the values of the terms “low”, “medium”, “high” from Table 2 into fuzzy logic equations for the linguistic variable G:

— for the term “low”

$\mu_{low}(G)=0.17 \wedge 0.14 \vee 0.17 \wedge 0.2=0.17$

— for the term “medium”

$\mu_{medium}(G) =0.14 \wedge 0.14 \vee 0.14 \wedge 0.2=0.14$

— for the term “high”

μ_{high} (G)=0.14 ∧ 0.12 ∨0.25 ∧0.12=0.12

For the highest level Q, the final values of the belonging functions will have the form:

— for the term “low”

μ_{low} (Q)=0.17 ∧0.14 ∧0.17 ∨0.12 ∧0.17∧0.17=0.14

— for the term “medium”

μ_{medium} (Q) =0.12 ∧ 0.14∧ 0.17∨0.2∧0.14 ∧ 0.14=0.14

— for the term “high”

μ_{high} (Q)=0.2 ∧ 0.2∧ 0.12 ∨0.2 ∧0.24∧0.12=0.12

To determine the numerical value of the evaluation of the quality of the implementation of the printed product manufacturing process, let’s perform the defuzzification of the fuzzy set according to the principle of the centre of gravity:

$$Q = \sum_{i=1}^{M} [Q + (i-1) \cdot (\Omega - \Omega)/m - 1]_{\mu_i} \cdot (Q) \cdot / \cdot \sum_{i=1}^{m} (Q) \quad (3)$$

where Q_{min} – the minimum value of the quality indicator; Q_{max} is the maximum value of the quality indicator; and m is the number of fuzzy terms.

As a result of the calculation, we will obtain the quantitative value ($Q_{predicted}$=48.56%) of the integral quality indicator of the printed product manufacturing process, provided that: m=3; μ_1(Q)=μ_{low}(Q); μ_{2low}(Q)=μ_{medium}(Q); μ_3(Q)=μ_{high}(Q): conditional limits for the variable Q^Q=1%; Q=100%. For the fuzzy estimation terms Q, let’s perform the calculation at three interval points: 1%, 50%, 100%.

Taking into account the formed set of research stages, the model of predictive assessment of the quality of production processes of printed products will include 8 stages: preprint, print and post-print technological processes; simulation of functions; synthesis of factors models; optimization of models; selection of alternative options for ensuring the quality of printed products; synthesis of models of fuzzy logic derivation; formation of integral indicators of the quality of printed products.

Thus, a structural-functional model of information technology for predictive assessment of the quality of technological processes at the stages of preprint, print and post-print has been developed, which considers the stages of research and enables a priori assurance of the quality of printed products.

Conclusions

1. As a result of the conducted theoretical and experimental studies, universal term sets of values and their corresponding linguistic terms were formed for linguistic variables (factors) of the processes of forming and obtaining high-quality printed products at the preprint, print and post-print stages.
2. By calculating the matrices of pairwise comparisons for each linguistic variable and its corresponding term-set of values, the values of the belonging functions of linguistic variables of the analyzed technological processes were obtained.
3. The value of the evaluation of the quality of the processes implementation of formation and production of printed products was obtained by defuzzification of fuzzy sets according to the principle of the center of gravity. The integral quality indicator of the quality formation process is 48.56%, and the integral quality indicator of the quality assurance process is 51.44% with maximum values of 100%.

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THE INFLUENCE OF THE TEXTILE SUBSTRATE COLOR ON THE CONTRAST OF THERMOCHROMIC PRINTS

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Abstract
Thermochromic inks have attracted much attention due to their application in various fields, including the textile industry. The application of these colors in sports clothing enables the monitoring of the athlete's physiological state through the possibility of changing the color of the material under the influence of skin temperature. Due to the printing of thermochromic inks on textile materials used for visual control, there is a need to analyze the contrast of the printed elements. Contrast plays a significant role in visually highlighting shapes and details and also facilitates the recognition of printed parts and information on textile materials. Contrast analysis of thermochromic inks on different colors of textile materials plays a role in determining the optimal combination of base colors and thermochromic inks that will result in the most noticeable color change. This analysis allows designers and manufacturers to make good decisions about choosing the colors of textile materials when printing with thermochromic inks because, in this way, a high level of aesthetics and functionality is achieved. This work aims to compare and analyze the contrast of thermochromic inks on different colors of the substrate of different types of materials, as well as to determine whether the color of the fabric on which the thermochromic ink is printed affects the color contrast when it is changed, i.e., its discoloration and return to its original state. Magenta reversible thermochromic water-based leuco dye was used to print the samples. The work used textile materials for printing with different structures and different colors. The colors were chosen to be bright and to provide a good contrast with the magenta color so that their combination attracts the viewer's attention and can create a strong visual effect. Colorimetric and contrast analyses determined that the color of the substrate is dependent on the contrast value. In the case of polyester textile material, the white color of the substrate showed the highest contrast values. On the other hand, in the case of printed samples on a material made of a mixture of polyester and elastane, it can be concluded that the gray color of the substrate gives the highest contrast values. In conclusion, the research high-

lights the importance of choosing colors and materials to achieve optimal results in the design and production of textile materials with thermochromic inks.
Keywords: *contrast, smart textile, thermochromic inks*

Introduction

Thermochromic materials represent a type of functional materials that can change color, color intensity, or transparency due to the action of a thermal stimulus and belong to the group of smart materials. Color changes can be reversible or irreversible (Hakami et al. 2022, Jakovljević et al. 2022). An example of thermochromic materials is thermochromic inks, which have found their application in many areas. In this paper, the focus will be on their application in the textile industry.

Thermochromic inks contain microencapsulated active material and thermochromic pigments dispersed in a reactive binder (Jakovljević et al. 2020, Rožić et al. 2017). There are two large groups of these inks, leuco dyes and liquid crystals (Elmaaty et al. 2018). Thermochromic dyes that are most often used in the textile industry are leuco dyes, which are capable of reacting to temperatures from –15°C to 60 °C. A key feature of thermochromic inks based on leuco dyes is their capacity to dynamically change properties in response to varying ambient temperatures, making them optimal for use in textiles. Another group of thermochromic inks consists of liquid crystals, which provide a continuously changing color spectrum when exposed to temperature changes due to the selective reflection of a certain wavelength of light by the crystal structure (Guan et al. 2019).

Due to the possibility of developing new creative design solutions, color-changing smart textiles are attracting huge interest due to their interaction, responsiveness, and ultimate functionality. Thermochromic inks find applications as temperature indicators, components in wearable electronics, within medical contexts, for fashion design, and in protective uniforms and materials. (Shahid & Adivarekar 2020). Its use in modern sports is significant, as it enables monitoring and improving the athlete's results while protecting them from possible injuries. Thermochromic inks have also found their application in the fashion industry due to the possibility of providing dynamic visual effects in terms of changing the design and its adaptation to changes in the temperature of the environment or the body.

When it comes to colors on textiles, contrast plays an important role in visual impression and aesthetic design. A strong contrast between colors can attract attention and create an interesting and dynamic look by creating a striking and attractive visual composition. Calculating contrast can be useful for understanding the visual differences between two colors. This paper aims to highlight the importance of the contrast between the color of the textile substrate and the printed thermochromic inks, which represents a visual signal for monitoring a condition.

Methodology and equipment

Research methodology implies objective methods of investigation. The samples were printed using a manual screen-printing technique, with a 120 threads/inch screen, using a reversible thermochromic magenta color based on a leuco dye. Textile materials of different raw material compositions and different colors (white, beige, gray, yellow, and purple) were used as printing substrates. The first textile material used is 100% polyester and has a thickness of 0.405 mm. The other material used is a mixture of polyester (97%) and elastane (3%), while the thickness of the material is 1,070 mm. A total of 30 samples were tested, three samples each for all five different colors of two types of material, to obtain mean arithmetic values. The samples had to be heated to achieve a thermochromic ink activation temperature of 31°C. For this purpose, a stone slab was used, which was placed on an induction stove that heated it. When the stone slab reached a temperature of 50°C, samples were placed on it and heated for 2 minutes so that the ink would activate and lose its coloration. After heating, the samples were removed from the stone slab to cool down gradually and to monitor the process of returning the color to its original state. In time intervals of 10 seconds, the colorimetric values of the prints were measured to determine the current color of the print. The Techkon SpectroDens device was used for colorimetric measurements of the samples. During the measurement, the value of the standard observer was set to 2°, the standard illumination to D50, and the polarizing filter was turned off. The experimental conditions included an ambient temperature of 22°C ± 2°C, a relative air humidity of 40% ± 2%, and atmospheric pressure of 101kPa ± 1kPa.

Colorimetric testing obtained CIELAB values, from which mean arithmetic values were calculated for each tested sample during data processing and subsequently utilized to determine the absolute color difference. This analysis aims to determine how color has changed over time and what effect different colors of printing substrates have on it. The color difference value (ΔE^*) was determined using the CIE ΔE formula provided below, where ΔL^* signifies the difference in brightness, Δa^* indicates the difference on the red/green axis, and Δb^* indicates the difference on the yellow/blue axis.

$$\Delta E^{*} = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$$

The color difference values were categorized as follows: ΔE < 0.2 (not visibly different), ΔE between 0.2 and 1 (the color difference is noticeable), ΔE between 1 and 3 (the color difference is visible), ΔE between 3 and 6 (the color difference is clearly visible), and ΔE over 6 (obvious color deviations) (Kašiković et al. 2014).

The measured colorimetric values were also used for contrast analysis on samples of different colors. Contrast analysis provides additional guidance for fabric color selection when using thermochromic inks on textile materials. The formula for calculating the contrast is given below:

Figure 1 shows the experimental setup.

$$Contrast = \frac{Color\ 1\ Lightness - Color\ 2\ Lightness}{Color\ 1\ Lightness} * 100\%$$

Figure 1 shows the experimental setup.

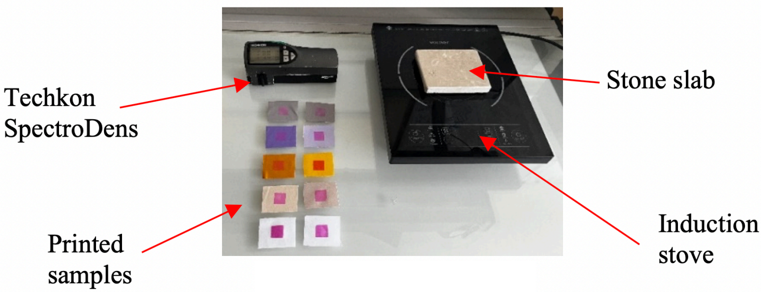

Fig 1. Experiment setup

Research results

Colorimetric analysis obtained CIELAB values, which were used to calculate the absolute color difference. The main goal of this analysis is to determine how the color of the print on different materials has changed over time. Figure 2 shows how the color of the samples on the beige substrate changed during cooling for one minute, with time intervals of 10 seconds each.

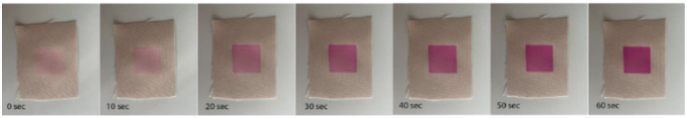

Fig 2. Display of color change in a time interval of one minute

Figure 3 graphically presents the color differences for the samples of different polyester colors. It can be noticed that the color change of the prints over time is not the same for all colors of the substrates and that the color change values increase as the print cools down, that is, as it recovers its coloring. The biggest color changes were recorded on prints printed on a yellow substrate, where the color difference was 50.94. The smallest color changes were measured on a print on a white substrate and amounted to 35.78. Also, considering that a color difference of more than five is considered a massive difference, with all prints in the first two intervals, the color difference is very noticeable. On the third and fourth intervals, all colors except yellow have a color difference of 1.49 to 3.02, which are characterized as very small and medium color differences. At all other intervals, with white, beige, gray, and purple, the color difference is very small, while with yellow, the difference is medium and can be noticed even by an untrained eye.

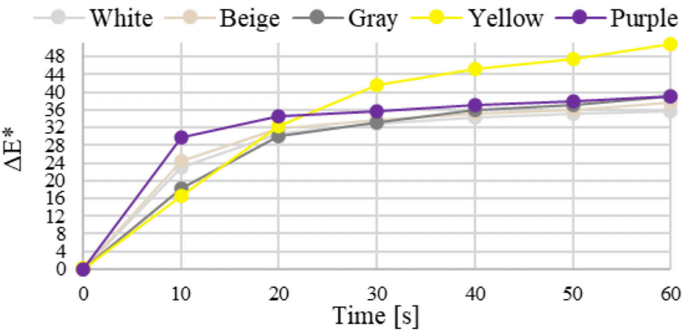

Fig 3. Comparative display of changes in absolute color difference over time for different colors of polyester textile materials

Prints on textile material made of a mixture of polyester and elastane require a longer cooling time to restore the color because the material has a greater thickness. Figure 4 shows how the color of the samples on the beige substrate, made of a mixture of polyester and elastane, was changed during cooling.

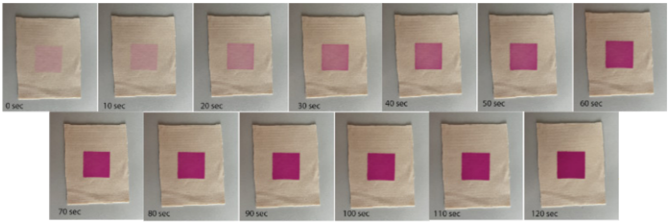

Fig 4. Display of color change in a time interval of two minutes

Figure 5 shows the color changes on prints printed on different colors of textile material made of a mixture of polyester and elastane during a time interval of 120 seconds. It can be seen on the graphic that even in this case, the color change is not the same for all samples. The most significant color changes were recorded on prints printed on a beige substrate, where the color difference was 49.57. The slightest color change was measured on the print on the purple substrate and was 27.05. By analyzing the other prints, it can be seen that the color change decreases with the change in material color from beige to white, yellow, and gray to purple.

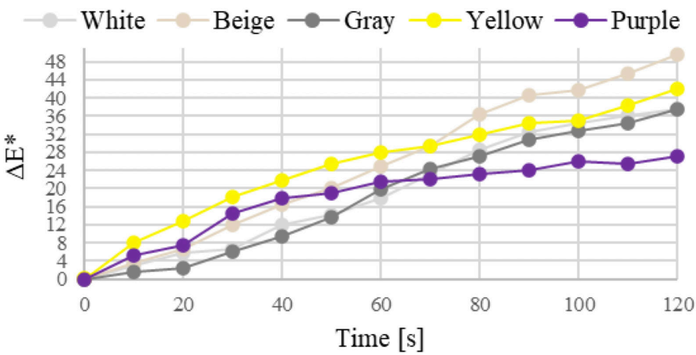

Fig 5. Comparative display of changes in absolute color difference over time for different colors of polyester-elastane blend textile materials

Contrast measurement is an important feature when choosing the color of the substrate for printing with thermochromic inks, as it enables the desired level of visibility of color change to be achieved. To calculate the contrast, the lightness values measured during the colorimetric measurement and the appropriate formula for calculating the contrast were used. The comparison is always made with the color of the substrate because it is important to monitor the contrast in relation to the substrate over time. The goal of the contrast analysis is to determine which substrate color for printed samples with magenta thermochromic ink gives the best contrast values when changing color. Figure 6 shows graphically the changes in contrast during the cooling time interval of the print on polyester samples.

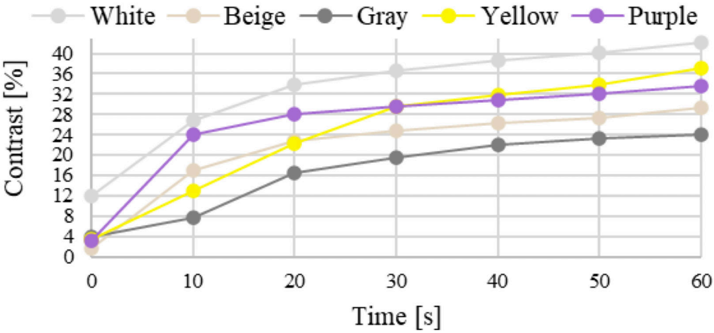

Fig 6. Graphic representation of contrast on samples printed on polyester textile material

Analyzing Figure 6, it is noticed that the contrast is the lowest at the first measurement interval, after which it increases drastically at the second and third measurement intervals for all colors of the substrate. After the third measurement interval, i.e., after 20 seconds of cooling the prints, the contrast values gradually increase. With the white substrate, a growth of about 2 % is observed at each subsequent time interval. The yellow substrate color at the fourth measurement interval still has a drastic increase in contrast by 7 %. Although there are significant increases in contrast over time, especially compared to the initial state, the contrast results are lower compared to the white substrate color. In the case of a print on a gray substrate color, after the third measurement interval, the contrast increases by 1 %, which is the smallest contrast change during the measurement time and the least noticeable change.

Figure 7 graphically presents the change in contrast over time for samples made of a mixture of polyester and elastane. It can be seen that all colors except yellow and purple have contrast values that increase over time. In the case of the print on the gray substrate, the highest contrast was recorded at the beginning compared to all other samples, but it also had a constant increase in contrast. The yellow substrate color in the first three measurement intervals gives the lowest contrast values compared to other colors, so it is not a good choice for contrast monitoring during color activation. The graphic shows that, in addition to gray, a purple substrate color can be used when following the mention of color around the activation temperature and in the first few seconds after heating the print. However, after reaching the activation temperature, the lowest contrast is expressed on the purple color of the substrate.

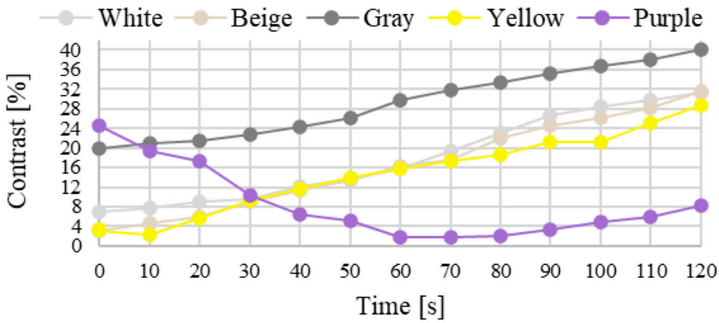

Fig 7. Graphic representation of contrast on samples printed on a polyester-elastane blend textile material

Conclusions

1. Contrast analysis of thermochromic inks on different colors of textile materials plays an important role in achieving the desired visual effects and functionality. A graphic representation of the contrast on different colors of the substrate of two different textile materials enables a clear view and comparison of the color contrast on different textile materials.
2. The highest contrast values on the polyester textile material within a 60-second time interval are given by the white color of the substrate, while the gray color of the substrate gives the lowest contrast values.
3. For samples printed on polyester and elastane blend textile material, it can be concluded that the gray color showed the best contrast both at the beginning and at the end of the measurement. Therefore, it gives good contrast results during both the cooling and heating of the print. Additionally, the white and beige colors are good because they have a constant and relatively even increase in contrast, while the yellow and purple colors of the substrate have variable contrast values during the cooling of the print, so they are not the best choice if a consistent change in contrast is desired.

Acknowledgment

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RECENT PROGRESS IN THE DEVELOPMENT OF COATINGS FOR PAPER FOOD PACKAGING APPLICATIONS

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Abstract
Relevance and aim of the research: Many types of coatings have been developed to meet the demanding needs and properties of paper-based packaging, which is the most widely used sustainable category of food packaging. The purpose of this paper is to list and classify special sustainable coatings, such as bio-based coatings and coatings based on nanomaterials (NPs) that provide barrier, optical, mechanical, anti-microbial and other properties as well as additional functions to the final product for food paper packaging.
Methodology and results: The study is an overview of the previously published works on trends and challenges in the development of healthy and eco-friendly for sustainable food paper packaging applications, which are green alternatives to conventional coatings. As known, paper/paperboard packaging, because of its structure made from cellulose fibers, is naturally sensitive to microbial attack due to the poor barrier properties (i.e., hydrophilicity, porosity, low grease resistance, high absorptivity to gases and water vapors). Thus, paper packages must be properly coated to withstand and keep the food safe, preventing temperature, humidity and other factors of the surrounding from affecting the composition of packaged food. However, the current market is based on the application of commonly used coatings, which are typically made from fossil oil or synthetic polymers, waxes and /or fluor-derivatives that improve surface hydrophobicity and barrier properties. Nowadays, the use of these materials is limited because of problems arising from fossil-oil resources, poor recyclability, and environmental issues. Therefore, these coatings must be replaced by new materials, with high biodegradability, recyclability and compostability features. Recent studies are focused on biopolymers including polysaccharides such as chitosan, starch, etc., proteins such as whey, wheat gluten, and zein, polyesters as polylactic acid (PLA), polycaprolactone (PCL), and polyhydroxyalkanoates (PHAs) that are investigated to formulate coatings with barrier properties for food packaging paper. Petroleum-based polymers are commonly used in paper coating. Due to the good affinity with the substrate,

they create suitable barriers to gases and aroma and increase the mechanical strength of the paper packaging. Moreover, biopolymer products have been developed as counterparts to smoothly replace petroleum-based polymers., they can be made from natural raw materials and sources, such as vegetal and marine biomass, this way they can be biodegradable, nontoxic. Additionally, they act as a basis for the incorporation of additives with specific functions for coated paper (ie, active-antimicrobial properties). The methods of chemical modification and combination as well as the processing and production of these new coatings for paper packaging are still under investigation. The addition of certain nanoparticles (NPs) such as metals and oxides in biopolymers and green coatings could be advantageous to add value and enhance the processing, performance and functionality of food paper packaging.

Conclusions & practical implications: The application of coatings on paper-based food packaging is extensively investigated to replace petrochemical derivatives by choosing environmentally friendly alternatives that come from natural and renewable resources. These options determine the ultimate recyclability, biodegradability and even compostability of the final product. The incorporation of certain nanomaterials in the coatings promises to provide a wide range of enhanced properties and improve barrier characteristics of the paper-based food packaging.

Keywords: *Barrier properties, Bio-based coatings, Nanomaterials, Paper food packaging, Sustainability*

Introduction

Paper-based packaging is the most widely used packaging for food and non-food products. However, for food packaging, there are obstacles to overcome. Paper-based packaging consists of very porous cellulose fibers, which easily absorb humidity. Moreover, the most important barrier properties the food packaging has to meet are moisture vapor transmission, liquid water resistance and oil and grease resistance. Therefore, the paper substrate is often coated with hydrophobic coating materials such as polyethylene (PE), polyvinyl alcohol, rub latex and fluorocarbon to improve their water vapor barrier or waterproof properties. Different types of coatings, such as water-based biopolymers, due to their greater environmental compatibility, are making inroads into more traditional petroleum-based wax and plastic laminate paperboard products for fresh food bakery, frozen food, and take-out container applications. In addition, nano-biocomposites have been studied at an accelerating pace for developing active and smart packaging.

Given the recent progress in the field, we can anticipate a robust pace of ongoing developments. Food packaging plays a crucial role in addressing the sustainability challenges associated with food consumption. Globally, approximately 55% of paper usage is dedicated to packaging, reflecting a recent trend toward reducing single-use plastics (Praveen, 2022).

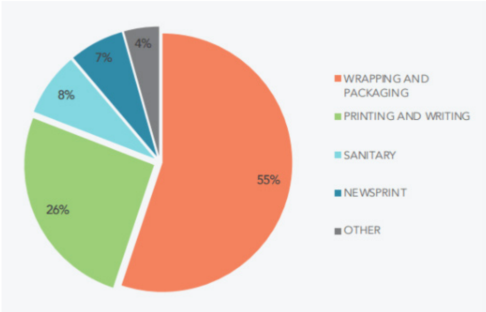

Figure 1: Global paper consumption: How paper affects the environment 2023. Source: Tappi.org

Nanotechnology has paved the way for the development of new architectures and unique patterns that eventually have yielded nano-structured and nanocomposite coatings with outstanding performances. From a sustainability perspective, the range of paper and paperboard products has expanded greatly through the rational use of these coating technologies. To render technological functionalities such as 'gas and moisture permeation resistance, hydrophobicity, antimicrobial protection, scratch resistance and cohesive strength', the paper-based surfaces of packaging are coated or treated with several conventional and non-conventional coating materials (Nassar, 2012).

Biopolymers including polysaccharides, proteins, and polyhydroxy-alkanoates (PHAs) can be used to formulate new pathways for the assembly of fully bio-based and functional paper coatings for food packaging. However, difficulties associated with the processing of most biopolymers in their pure form may arise from hydrophilicity, crystallization behavior, brittleness or melt instabilities, sealability, etc., that hinder full exploitation at an industrial scale. As an option to enhance the behavior of biopolymers, certain classes of nanomaterials (NPs) such as metals (Ag, Au, Cu), oxides (ZnO), nano-clays (NCs) and nano-emulsions (NEs) have numerous applications to add value to the manufacturing of active food packaging (He Y, 2022). Nanocomposites, a fusion of traditional food packaging materials with nanoparticles, are gaining interest in the food packaging sector because, in addition to their remarkable antimicrobial spectrum of activity, they display great mechanical performance and strong resistance characteristics to external influences (e.g., heat, pressure, pH, salinity, etc.) (Nassar, 2012).

1. Biodegradable coatings classificaton

Biodegradable polymers, which break down naturally in the environment, offer several advantages over traditional plastics. These include properties like conventional plastics, preservation of fossil fuels, and reduced environmental pollution. In contrast, synthetic polymers, derived from petroleum, are often non-biodegradable. However, researchers are increasingly interested in nature-derived polymers (such as chitosan, cellulose, and starch) due to their biodegradability, abundance, and sustainability. These natural polymers, with their high thermo-processibility, find applications in areas like packaging and biomedical implants, contributing to a greener, more sustainable future. Examples of such nature-derived polymers or biopolymers that can be processed into coating include proteins, polysaccharides (e.g., starch, chitin, cellulose and derivatives), lignin, natural rubber etc. Aliphatic polyesters, such as poly(lactic acid) (PLA) and polyhydroxyalkanoates (PHAs) (e.g., polyhydroxybutyrate (PHB), polyhydroxybutyrate valerate (PHBV), etc.), bio-derived poly(butylene succinate) (PBS) (Praveen, 2022).

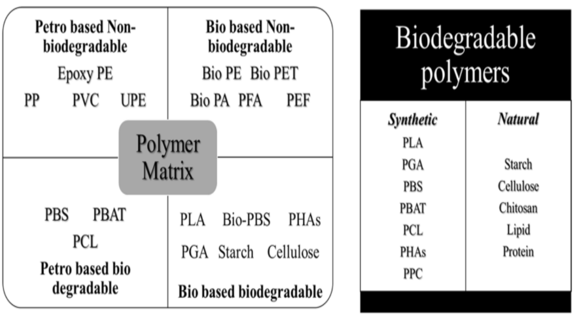

Fig.2 Classification of different kinds of coatings such as biodegradable and non-biodegradable and classifications of biodegradable polymers based on origin such as synthetic and natural.

2. Barrier Properties

Barrier properties are essential for maintaining food quality and safety. Packaging systems with optimal barrier properties protect their contents against water vapour, gases, light, and aroma compounds. Many polymers such as polyolefins (polyethylene, polypropylene), poly(vinyl chloride), aliphatic polyamides, poly(ethylene terephthalate), polycarbonate, and others are used as protective barrier films against the mass transport of small molecules of gases, vapours, and liquids. For paper packaging materials, the water vapor transmission rate (WVTR) is one of the most crucial barrier properties (Tyagi, 2021). When water vapor passes through the package, it affects the freshness of food and also increases the growth of microbes that spoil the food. Moisture reduces the shelf life of the food materials promoting undesirable reactions like oxidation and vitamin degradation. As paper is made of fibers, it alone cannot provide sufficient barrier properties for packaging applications. So, different coating materials are tried to improve the water vapor barrier properties.

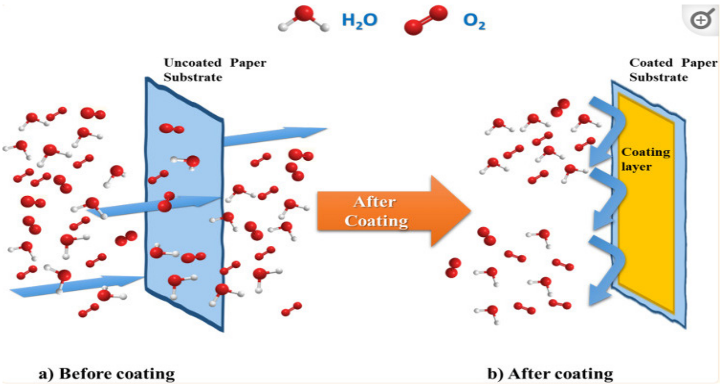

Fig.3 Barrier properties of paper before and after the coating application

For packaging applications, the barrier properties of paper play an essential role in preserving the freshness of the product and extending shelf life. The main barrier properties important for packaging are water vapor transmission rate (WVTR) and oxygen transmission rate (OTR) (Praveen, 2022).

3. Polysaccharides Based Coatings

Among the materials studied to develop biodegradable packaging films and coatings are polysaccharides such as cellulose, chitosan, starch, pectin and alginate. These polysaccharides can form films and coatings with good barrier properties against the transport of gases such as oxygen and carbon dioxide.

Polysaccharides can be classified according to their source, dividing them into four categories, namely plant, algal, animal, and microbial polysaccharides (Nechita, 2020).

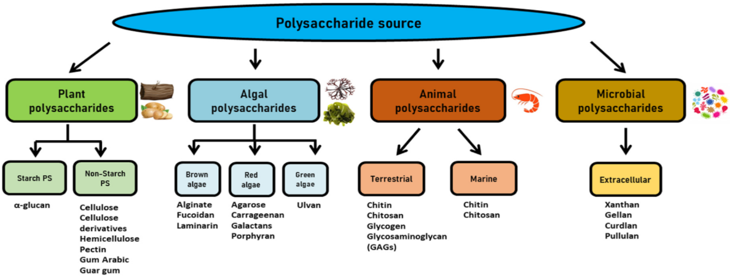

Fig.4 Classification of polysaccharides according to the sources.

Recent studies have provided an extensive experimental review of the main functional properties of the most promising polysaccharides for potential application in the field of food packaging. Their permeability to water vapour and oxygen, as well as their mechanical and optical properties, were measured under standardized conditions for poly-saccharide films with different percentages of glycerol used as a plasticizer. SA (Sodium Alginate) presented the highest oxygen barrier, with permeance values comparable to those of conventional high oxygen barrier plastics, such as EVOH (ethylene Vinyl Alcohol) and PVDC (Polyvinylidene chloride). The most promising application of polysaccharides could be their use as coating materials on paper-based packaging, offering a good protective barrier against oxygen for oxidation-sensitive food products. They might also help in the strategies to replace conventional coating materials, which are based on synthetic polymers, leading to recyclability issues for such multilayer materials (Wu Y, 2023).

4. Protein-Based Coatings

Protein-based films and coatings have gained significant attention in recent years as sustainable alternatives to conventional plastic packaging materials. These materials are derived from protein sources like casein soy, collagen, agricultural and other byproducts. These biomaterials offer a wide range of applications across different industries. For food packaging applications, the most interesting segments are the biodegradability and functionality, that these biomaterials can provide. Additionally, protein-based coatings can enhance the appearance, texture, and preservation of food items. They help prevent moisture loss, inhibit oxygen permeation, and reduce the transfer of unwanted odors or flavors (Purewal, 2024).

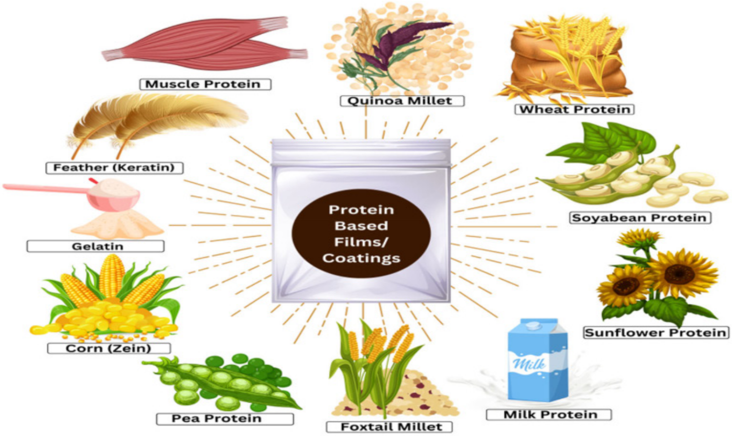

Fig.5 Sources used in the preparation of protein-based films / coatings.

Ongoing research and development efforts continue to enhance the properties, functionality, and application potential of edible coatings and films, further solidifying their position as an environmentally friendly alternative to conventional packaging materials. Each protein source possesses unique characteristics that impact the film properties, like the strength, barrier performance, and film-forming ability. These films act as edible barriers that protect food products from moisture loss, oxygen exposure, and microbial contamination (Wu Y, 2023). They are particularly useful for extending the shelf-life of perishable foods, such as fruits, vegetables, meats, and dairy products. These may include plasticizers for improved flexibility, cross-linking agents for enhanced mechanical strength, and bioactive compounds for antimicrobial or antioxidant properties. Such modifications expand the potential applications of protein-based films, including controlled-release systems and active packaging.

5. Polyesters

Polyester barrier coatings play a significant role in food paper packaging. These coatings, including Polyethylene terephthalate (PET), provide excellent oxygen barriers, durability, and heat resistance. Additionally, researchers explore bio-based alternatives, such as Poly Lactic Acid (PLA) and polyhydroxyalkanoates (PHAs), which offer biodegradability and sustainability. Dispersion barrier coatings are also gaining prominence, reducing plastics in food packaging. Polyhydroxyalkanoates (PHAs), these bio-based materials are synthesized by various prokaryotic microorganisms and offer several valuable properties, such as biocompatibility. PHAs are bioresorbable, meaning they can be broken down naturally over time. When exposed to natural conditions (such as soil, water, or compost), PHAs break down into harmless components (Kunam, 2022). This process contributes to sustainability and reduces plastic waste. In summary, PHAs offer a promising avenue for sustainable materials in various fields, from medicine to packaging. Their ability to balance biocompatibility, bioresorbability, and biodegradability makes them a valuable resource for a greener future. Poly(lactic acid) (PLA) is a bioplastic with several noteworthy properties. It is derived from lactic acid molecules, which are fermented from plant matter under controlled conditions. PLA breaks down naturally after use, without harming the environment. PLA is made from renewable resources, contributing to sustainability. It serves as an alternative to petroleum-based plastics in various fields, including packaging and consumer goods. In conclusion, PLA offers a versatile and eco-friendly solution, bridging the gap between functionality and sustainability (Praveen, 2022).

6. Nanocomposites

Nanocomposites have become a promising avenue for enhancing food packaging materials. The industry aims to create sustainable packaging solutions that contribute to a circular economy by reducing traditional plastic consumption while maintaining desired properties. Nanocomposites are nanoparticles (NPs) that are incorporated into polymer matrices. They offer improved functionalities and can potentially replace complex multilayered polymer structures. Incorporating low concentrations of nanofillers significantly improves the barrier, mechanical, and thermal properties of polymers. Nanocomposites can introduce antimicrobial and antioxidant features relevant to food packaging. Some biopolymer nanocomposites are thermoplastic starch, which is widely studied and suitable for packaging (Chollakup, 2021).

Conclusions

Bio-polymer composite coatings for paper represent a sustainable alternative, providing the opportunity to obtain barrier properties (low oxygen and water vapor permeability) and specific functionalities for fully protective food packaging. The application of coatings on paper-based food packaging is extensively investigated to replace petrochemical derivatives by choosing environmentally friendly alternatives that come from natural and renewable resources (Praveen, 2022). These options determine the ultimate recyclability, biodegradability and even compostability of the final product. The incorporation of certain nanomaterials in the coatings promises to provide a wide range of enhanced properties and improve barrier characteristics of the paper-based food packaging.

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LEVERAGING THE TEAMWORK MODEL FOR EFFECTIVE INTEGRATION OF INTERACTIVE MATERIALS ON MOBILE DEVICES IN VISUAL MEDIA COMMUNICATION, INNOVATION, AND IMPACT ON SOCIETY

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Abstract
The issue of waste in printed materials can be effectively addressed by leveraging technology, especially mobile devices, in language learning initiatives. This research focuses on integrating interactive materials through the TEAMWORK model, with the ELENE project serving as a case study. The overarching goal is to assess how the TEAMWORK model can streamline planning and execution in mobile-assisted language learning endeavours. By evaluating effectiveness, identifying challenges and best practices, and offering practical recommendations, this study aims to improve language education outcomes through technology integration while reducing the environmental impact associated with traditional printed materials.
The research methodology involves a thorough examination of integrating interactive materials on mobile devices using the TEAMWORK model, with a specific focus on the ELENE project. It commences with a comprehensive literature review and progresses to qualitative data collection through interviews and observations. The TEAMWORK model serves as a guiding framework for planning and execution, with data gathered through surveys and usage analytics. Analysis techniques are employed to evaluate the model's impact on project outcomes and to derive practical recommendations for stakeholders, all aimed at enhancing language education practices and technology integration.
The research results highlight the effectiveness of integrating interactive materials on mobile devices using the TEAMWORK model, as evidenced by the ELENE project. Qualitative analysis revealed that the structured approach provided by the TEAMWORK model significantly improved planning and execution phases, leading to better project outcomes and increased learner engagement. Quantitative data further corroborated these findings, demonstrating measurable enhancements in language proficiency and user satisfaction. Challenges such as technical constraints and resource limitations were effectively managed through proactive risk mitigation strategies

outlined by the model. Overall, the results underscore the value of the TEAMWORK model in optimizing mobile-assisted language learning initiatives and offer valuable insights for stakeholders involved in similar endeavours. The integration of interactive materials on mobile devices, guided by the TEAMWORK model within the ELENE project, has significantly improved language learning outcomes. Through structured planning and execution, the TEAMWORK model effectively enhanced project outcomes and increased learner engagement. Practical implications include actionable recommendations for stakeholders involved in similar projects, offering insights for maximizing the effectiveness of technology integration in language education.
Keywords: *ELENE project, interactive materials, mobile devices, TEAMWORK model*

Introduction

In the evolving landscape of education, the fusion of technological advancements and environmental awareness has sparked a significant transformation in our approach to teaching and learning. Nowhere is this more apparent than in language education, where the traditional reliance on printed materials faces increasing scrutiny due to growing environmental concerns. As societies globally embrace digitalization, the imperative to mitigate the environmental impact of educational practices while enhancing learning outcomes becomes increasingly urgent (Sinha et al., 2020).

At the forefront of this paradigm shift is the exploration of alternative methodologies that harness technology to revolutionize language learning. One such approach is integrating interactive materials through the TEAMWORK model, offering a sustainable solution to the challenges posed by waste in printed materials. This model, which underscores Technology Integration, Engagement, Accessibility, Multimodality, Workflow Optimization, and Real-time Feedback, provides educators with a structured framework to effectively utilize technology in language education initiatives (Tuma, 2021).

Inspired by successful endeavours like the ELENE [Elders Learning English for Europe] project (Jakob, et.al., 2023), which exemplifies seamless technology integration in education, this research aims to apply the principles of the TEAMWORK model to language learning contexts. Our goal is not only to diminish the environmental impact associated with traditional printed materials but also to enhance the efficacy and inclusivity of language education worldwide (Guan et al., 2020).

This paper will delve into the rationale behind leveraging technology to tackle the challenges of waste in printed materials within language learning initiatives. The key components of the TEAMWORK model and elucidate how they can be adapted to cultivate interactive and sustainable learning experiences will be analysed. Additionally, the ELENE project as a case study, extracting insights and lessons that can guide the implementation of the TEAMWORK model in language education will be scrutinized. Through this examination, we endeavour to contribute to the ongoing discourse on sustainable educational practices and pave the way for a more environmentally conscious and technologically empowered future in language learning (Siguencia et al., 2023).

Methodology approach

This study adopted a mixed-methods research approach, incorporating both qualitative and quantitative methodologies to fulfil its objectives. The researchers initiated an extensive literature review, synthesizing existing literature to establish the theoretical framework and identify pertinent research findings concerning language education, sustainability, technology integration, interactive learning materials, visual media communication, innovation, and impact on society. This process involved integrating research from various disciplinary perspectives to shape the conceptualization of the research problem and formulate hypotheses (Guan et al., 2020).

The analysis of the ELENE project and other relevant case studies provided valuable insights into successful technology implementations in education, particularly within language learning contexts. These insights guided the development and adaptation of the TEAMWORK model for this study, offering practical guidance for its implementation and evaluation (Jakob et al., 2023).

Surveys and interviews were employed to collect data on stakeholders' attitudes towards printed materials, technology integration, and preferences for interactive learning materials. These insights offered valuable context for comprehending the challenges and opportunities associated with integrating interactive digital materials into language education (Akram et al., 2022).

To quantify the ecological footprint of traditional printed materials used in language education, an environmental impact assessment was conducted. This analysis furnished empirical evidence to advocate for transitioning towards more sustainable practices and the incorporation of interactive digital materials (Sherman et al., 2020).

Experimental studies were devised to assess the effectiveness of interactive digital materials in enhancing language learning outcomes, including engagement, comprehension, and retention. The research aimed to offer evidence-based recommendations for stakeholders on the pedagogical benefits of technology integration. Ensuring consistency, reliability, and ethical considerations, the research was conducted in controlled environments, with stringent measures in place (Figueiredo, 2023).

Research results

This study utilized a mixed-methods research approach, integrating both qualitative and quantitative methodologies to accomplish its objectives. A comprehensive literature review was undertaken to establish the theoretical framework and identify relevant research findings about language education, sustainability, technology integration, interactive learning materials, visual media communication, innovation, and impact on society. This process involved synthesizing research from diverse disciplinary perspectives to inform the conceptualization of the research problem and the development of hypotheses (Guan et al., 2020).

The analysis of the ELENE project and other pertinent case studies provided insights into successful technology implementations in education, particularly within language learning contexts. This analysis guided the development and adaptation of the TEAMWORK model for this research, offering practical insights for its implementation and evaluation (Siguencia et al., 2023).

Surveys and semi-structured interviews were employed to collect data on stakeholders' attitudes towards printed materials, technology integration, and preferences for interactive learning materials. These insights furnished valuable context for understanding the challenges and opportunities associated with integrating interactive digital materials into language education (Akram et al., 2022).

An environmental impact assessment was conducted to quantify the ecological footprint of traditional printed materials used in language education. This analysis provided empirical evidence to support the argument for transitioning towards more sustainable practices in language education and highlighted the potential environmental benefits of leveraging technology to reduce reliance on printed materials (Sherman et al., 2020).

Experimental studies were designed to evaluate the effectiveness of interactive digital materials in enhancing engagement, comprehension, and retention among language learners. These studies involved controlled experiments with participant groups exposed to different types of learning materials, followed by assessments of learning outcomes. The research was conducted in controlled environments, and measures were taken to ensure consistency, reliability, and ethical considerations (Figueiredo, 2023).

Overall, the mixed-methods approach employed in this study provided a comprehensive and rigorous analysis of the research problem, leveraging both qualitative and quantitative data to inform the development, implementation, and evaluation of the TEAMWORK model in the context of the ELENE project.

The findings of the environmental impact assessment on traditional printed materials used in language education highlighted the significant environmental challenges associated with their excessive use. These challenges included deforestation, increased greenhouse gas emissions, and waste accumulation. Such evidence strengthened the rationale for exploring alternative approaches, such as the integration of interactive digital materials on mobile devices, to minimize environmental impact while enhancing language education effectiveness (Sinha et al., 2020).

The key recommendations made in the environmental impact assessment on traditional printed materials used in language education were:

Key recommendations	Description
Digital Solutions in Language Learning	Leverage technology, particularly mobile devices, to integrate interactive digital materials and reduce reliance on printed materials in language learning initiatives. The assessment highlighted the potential environmental benefits of transitioning towards more sustainable digital alternatives
Optimizing Mobile Language Learning with TEAMWORK	Integrate the TEAMWORK model, a comprehensive framework for Adult Education Cooperation Partnerships (AECPs), to optimize the planning and execution of mobile-assisted language learning endeavours. The structured approach of the TEAMWORK model was recommended to improve project outcomes and learner engagement.
Evaluating Eco-Impact in Language Education	Conduct a thorough environmental impact assessment to quantify the ecological footprint of printed materials used in language education. The assessment provided empirical evidence to support the transition towards more sustainable practices and the integration of interactive digital materials.

Digital Materials in Language Learning	Implement rigorous experimental studies to evaluate the effectiveness of interactive digital materials in enhancing language learning outcomes, such as engagement, comprehension, and retention. The research aimed to provide evidence-based recommendations for stakeholders on the pedagogical benefits of technology integration.
Enhancing Language Education with Technology	Offer practical recommendations for stakeholders involved in similar mobile-assisted language learning initiatives to maximize the effectiveness of technology integration and minimize the environmental impact. The research sought to provide valuable insights for enhancing language education practices through technology-driven solutions.

By integrating interactive digital materials and reducing reliance on printed materials through the use of technology, particularly mobile devices, significant improvements can be achieved in language learning initiatives. The implementation of the TEAMWORK model provides a structured approach to optimize planning and execution, ultimately improving project outcomes and learner engagement. Furthermore, conducting thorough environmental impact assessments highlights the potential benefits of transitioning towards more sustainable digital alternatives.

Rigorous experimental studies further underscore the effectiveness of interactive digital materials in language learning. Ultimately, this research offers practical recommendations for stakeholders to maximize the effectiveness of technology integration while minimizing environmental impact, thus contributing to the advancement of language education practices through technology-driven solutions.

Conclusions

The integration of interactive materials on mobile devices, guided by the TEAMWORK model within the ELENE project, has yielded significant enhancements in language learning outcomes. Through a comprehensive mixed-methods research approach, this study has furnished robust empirical evidence regarding the efficacy of the TEAMWORK model in optimizing the planning and execution of mobile-assisted language learning initiatives.

Qualitative analysis unveiled that the structured approach of the TEAMWORK model markedly improved various phases of the project, encompassing team formation, goal setting, resource allocation, monitoring and communication, work execution, outcome evaluation, risk management, and knowledge sharing. This structured framework facilitated the effective navigation of the complexities within the ELENE initiative, resulting in enhanced project outcomes and heightened learner engagement.

The quantitative data further validated these findings, showcasing tangible enhancements in language proficiency and user satisfaction among the participants of the ELENE project. Additionally, the environmental impact assessment conducted in this research highlighted the potential benefits of leveraging technology to diminish reliance on traditional printed materials, thereby reducing the ecological footprint associated with language education.

By identifying and addressing challenges such as technical constraints and resource limitations through proactive risk management strategies, the TEAMWORK model demonstrated its adaptability and resilience during real-world project implementation hurdles. The insights gleaned from this research furnish valuable recommendations for stakeholders engaged in similar mobile-assisted language learning initiatives, offering guidance on maximizing technology integration effectiveness while ensuring sustainable practices.

The outcomes of this study underscore the significant value of the TEAMWORK model in optimizing the planning and execution of mobile-assisted language learning endeavours. The comprehensive framework, with its emphasis on stakeholder engagement, alignment with program priorities, effective communication, and other critical components, has proven to be a robust and adaptable approach for augmenting language education outcomes through technology integration.

This research contributes to the expanding knowledge base concerning the intersection of language education, sustainability, and technology-driven solutions. By showcasing the efficacy of the TEAMWORK model within the ELENE project context, this study furnishes a blueprint for stakeholders aiming to leverage mobile devices and interactive materials to enhance language learning while concurrently minimizing the environmental impact of traditional printed materials. The practical implications and recommendations presented in this paper can inform the design and implementation of future mobile-assisted language learning initiatives, fostering positive change within the realm of language education.

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STABILITY OF THE CASH REGISTER RECEIPT DEPENDING ON THE THERMAL PAPER USED

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Abstract
The consumption of thermal paper has globally increased due to a wide variety of commercial applications including point-of-sale (POS) receipts, luggage tags, faxes, and labels. This type of paper is specially used for cash register printing paper and therefore its quality directly affects the quality of printing, stability and resistance during storage of receipt printouts. Often such prints end up in the trashcan very quickly after a purchase, but sometimes is an interest in saving them after buying products that have a guaranteed period of 2 years or more. Therefore, in this study, the comparison of two different cash register thermal papers (white and blue) was made based on paper characteristics, while the stability on them printed receipt was determined based on the change in colorimetric values after their exposure to a certain treatment. Three types of stability analysis were done which include sample exposure to light, pressure and water. Since colorimetric changes in the colour of cash register thermal paper and receipt are a visible sign of their quality degradation, the influence of contact with water, pressure and light was observed through ΔE*00. Under the influence of water and light cash register receipt on white thermal paper faded but stayed permanent on blue one. Also, receipts printed on blue thermal paper were more stable to rub and there was less colour transfer. It has been proven that blue cash register thermal paper is more stable than white one, and so are the receipts printed on that type of thermal paper.
Keywords: *cash register receipt, thermal paper, stability*

Introduction

The consumption of thermal paper has globally increased due to the rising use of POS terminals. Thermal paper is specially used for cash register printing paper so the global mass daily use of this type of paper is not surprising. Although it looks very similar to ordinary white paper, thermal paper is structurally different because it consists of several layers. The thermosensitive printing paper used in the cash register is generally divided into three layers (Hormann et al, 2014): the paper base as the bottom layer, precoat or base coat applied to the base paper for smoothness which prevents the heat transfer through all of the paper's layers, and the thermosensitive coating which contains all the components for colorization (Campbell et al, 2021). For some applications, it may contain a protective top coat and/or back coat (Online, 2015). The top impact on the quality of register thermal paper and with that cash register receipt has the thermosensitive coating. Namely, this coating consisted of thermochromic colours based on leuco dye, colour developer and sensitizers where the chemical reaction is in a "latent" state improving thermal insulation, smoothness, uniformity and strengthening of the thermal layer. It is responsible for the black colour that appears on thermal paper when printing. One of the most used colour developers in thermal papers is bisphenol A (BPA) or its replacement bisphenol S (BPS). Considering that BPA is a harmful chemical, its use is being tried to be reduced, therefore there are also papers without BPA or BPS coating (Frankowski et al, 2020). BPA exposure from handling thermal paper estimates typically daily dermal exposures of 59 ng/kg body weight, while the dermal uptake levels are 51.1 ng/kg body weight after one handling event (Bernier, Vandenberg, 2017). The purpose of the thermal layer is to produce text or images with a thermal reaction. The change in colour is caused by the composition of the paper in contact with heat, so exposing the paper to temperatures above 70 °C causes the coating on the paper to change colour (paper gets darker). Since it is a reaction to heat, these papers do not use ink, toner, or an ink cartridge, but are printed with the heat of a thermal printer. The text or image is created at the moment when the heat is directly transferred to the thermal paper, without printing ink, when the selected area of the thermal paper passes through the thermal print head. The higher the thermal sensitivity of the paper, the higher the quality and resolution of the print. Most thermal papers globally used cannot be recycled because they contain certain chemicals that make it difficult or completely impossible to recycle. The exception is 'blue' thermal papers with the FSC mark, in the production of which the same chemicals are not used. However, like any paper, thermal paper is degradable.

In this study, the focus was on testing the mechanical stability (rubbing), chemical stability (to water) and stability to light of cash register receipts printed on two different thermal papers. The change in colorimetric values were measured on a certain area of receipt (QR codes) before and after exposure to a certain treatment, because colorimetric changes in the colour of paper or prints are a visible sign of their quality degradation and can be more or less pronounced due to rubbing, contact with water and light.

Methodology and equipment

Two types of cash register thermal paper (CRTP) that differ in colour, were used as samples for this study. White and blue CRTP were selected as they are mainly used for cash register receipts in local supermarkets in Zagreb. According to ISO standards, grammage by analytical balance KERN ABT 220-4NM (ISO 536:2019), thickness by micrometre DGTB001 Thickness Gauge, Enrico Toniolo S.r.l (ISO 534:2011), smoothness by PTA line BEKK tester (ISO 5627:1995), colorimetric values CIE L*a*b* by x-Rite SpectroEye spectrophotometer and brightness by PCE-WNM 100 whiteness meter (ISO 2469:2014) were determined. Results gained on ten samples of each thermal paper were presented as a mean value with standard deviation.

The cash register receipts were collected in the period of two weeks before the beginning of the research to make sure that samples were not of impaired quality as well as to reduce the exposure to atmospheric influences before the testing. Collected samples were subjected to tests for water resistance, light and rubbing. Before testing, spectrophotometric values were measured for all samples to use them to define the stability of the prints. Spectrophotometric values were measured on QR codes as the largest printed surface of the cash register thermal paper. The chemical stability of cash register thermal papers and printed receipts was tested according to the ISO 2836:2004 standard. After the chemical stability test (24 hours standing between 4 soaked filter papers in distilled water under a load of 1 kg), samples were dried in the Memmert UNB 400 Supervision oven at a temperature of 40 °C for 30 minutes. Resistance to rubbing according to the BS3110 standard was performed on the Hanatek RT4 Rub and Abrasion Tester, where white photocopy paper was used as the material against which the tested print on thermal paper was rubbed. Samples in QR code areas were cut into circles with a diameter of 50 mm, and photocopy paper into larger circles with a diameter of 115 mm. During the test, the tested sample and photocopy paper were placed on discs, whereby the pressure was regulated using weights in such a way that weights of different masses were placed on the upper disc. The ink from the cash register receipt, which was removed from the surface due to rubbing, was transferred to white photocopy paper, at a pressure of 0.5 and 2.0 psi. (3.5, and 13.8 kPa). After 50 revolutions, the device was stopped. The light stability test was performed by exposing the samples to natural sunlight on a window oriented to the southern side in five different intervals of time (1, 7, 14, 21 and 28 days), under temperature conditions that varied throughout the day (from 20.8 ˚C to 33 ˚C).

The colorimetric colour differences after all three treatments (exposure of the samples to water, pressure, and light) were determined based on spectrophotometric values, and the samples were again subjected to spectrophotometric analysis after each treatment. The stability of the samples was observed based on the colorimetric difference, i.e. the Euclidean difference in the colour of the samples before and after treatment, where L* represents the brightness (L* = 0 for black and L* = 100 for white), and the chromaticity of the colour is defined in relation to the neutral axis value 0 and that CIE a* is the coordinate for red-green, and CIE b* for yellow-blue.

For the quantitative calculation of the difference in the colour of the samples after a certain treatment, the formula was used:

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

Where: $\Delta L'$ – the difference in brightness of the sample before and after a certain treatment; $\Delta C'$ – the difference in saturation of the sample before and after a certain treatment; $\Delta H'$ – the difference in tone of the sample before and after a certain treatment; R_T – rotation function; k_L, k_C, k_H – factors for variation in experimental conditions; S_L, S_C, S_H – weight functions for brightness, chromaticity, and tone.

Since the colorimetric changes in the colour of paper and prints are a visible sign of their quality degradation, therefore, the influence of contact with water, pressure and light on thermal paper and receipt stability is monitored via ΔE^*_{00}. If the value of ΔE^*_{00} after treatment is higher than 2, the change in colour starts to be visible to the average human eye. The values higher than 5 present a very visible colour difference of the sample with obvious deviations in colour.

Table 1. Basic characteristics of cash register thermal paper (CRTP)

Characteristic	CRTP	
	White	Blue
grammage (g/m^2)	45.22 ± 0.33	47.90 ± 0.97
thickness (mm)	0.05 ± 0.00	0.05 ± 0.00
Bekk smoothness (sec)	100.98 ± 3.04	26.22 ± 5.93
ISO brightness	83.88 ± 0.23	39.68 ± 0.51
L*	94.78 ± 0.24	63.84 ± 0.82
a*	0.02 ± 0.08	-3.84 ± 0.04
b*	-1.85 ± 0.13	-10.21 ± 0.23

Results

In Table 1, the results of basic characteristics for both types of analysed CRTP are summarized.

From the results shown in Table 1, it is evident that both types of CRTP are of equal grammage and thickness. As expected, due to the coloration after which the white and blue CRTP are named, they have different brightness and colorimetric CIE L* a* b* values. White paper is much brighter and has lower CIE a* and CIE b* chromaticity values (closer to the neutral axis, which has a value of zero), while blue paper is of reduced brightness and high colour chromaticity value on the CIE b* coordinate for yellow-blue. A surprising characteristic by which the analysed values of thermal papers differ greatly is smoothness. Namely, the smoothness value determined by the Bekk method is almost 4 times higher for white than for blue CRTP.

The chemical stability of cash register receipts significantly depended on the type of thermal paper used. The printing on the white CRTP almost disappeared in the areas of printed letters and numbers, while the more massively printed areas of QR code and store logo had lost colour intensity but were still visible (Figure 1a). Printing on blue CRTP on all observed areas of the receipt (QR code, barcode, letters and numbers) was stable and of unimpaired quality for legibility after testing (Figure 1b).

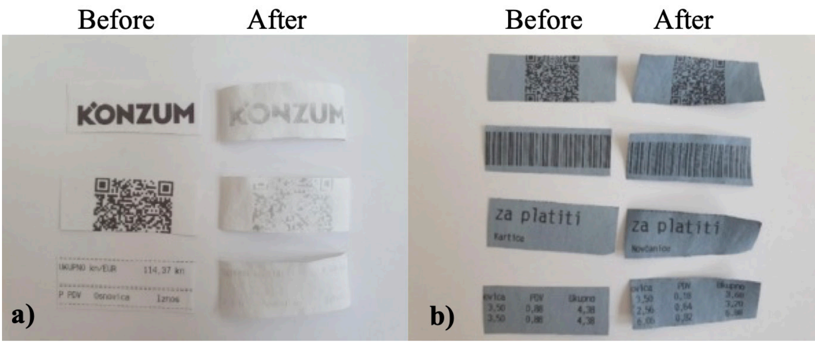


Fig 1. Pictures of receipt samples before and after treatment with distilled water: a) white CRTP; b) blue CRTP

Since the cash register receipts come from two different stores, which already distinguishes in the start in dimensions of the letters and numbers, QR codes, logos and barcodes, due to the type of device used for the colorimetric measurements we only chose the biggest printed areas (QR codes). The same measurements were also carried out on the unprinted parts of the receipts to see the impact of water on the papers themselves. The results of changes in the colour of these areas compared to the initial not treated are expressed in Figure 2 as ΔE^*_{00}.

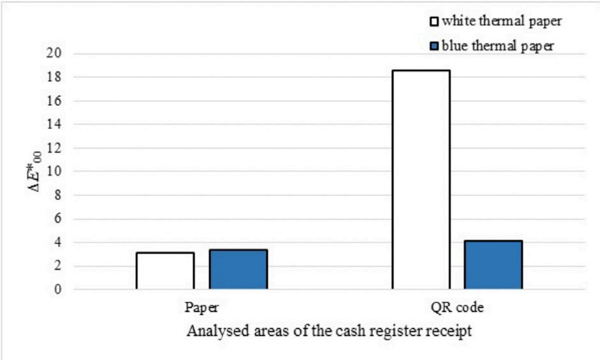


Fig 2. The influence of distilled water on the chemical stability of the cash register receipt

Although the ΔE^*_{00} results showed that the water stability of white and blue CRTP is equal (for white thermal paper (ΔE^*_{00} was 3.09 and for blue it was 3.34), the stability of prints on them in contact with water is drastically different. Prints on blue CRTP are far more stable. Calculated ΔE^*_{00} for QR code on blue CRTP after contact with distilled water was 4.1, while it reached even 18.6 for QR code printed on white CRTP.

Similar to the treatment with water, after exposing the samples to sunlight there were changes that are visible to the naked eye, which are much more pronounced on the cash register receipt printed on white CRTP (Figure 3).

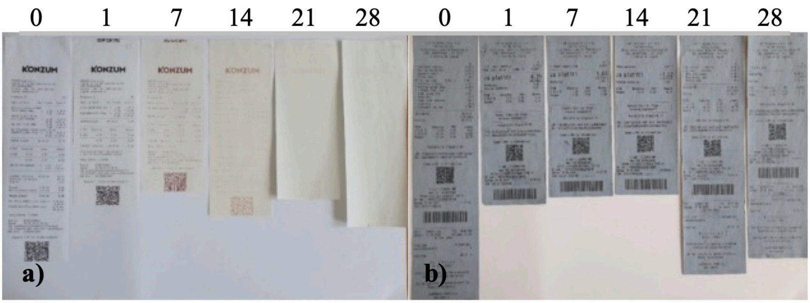
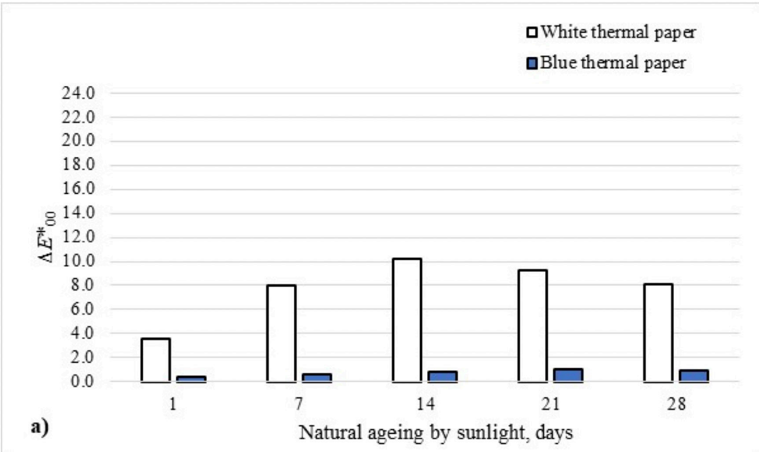


Fig 3. Pictures of receipt samples before and after treatment with sunlight: a) white CRTP; b) blue CRTP

The picture shows the gradual degradation, that is, how the paper aged, considering how many days each sample was exposed to sunlight.

To confirm the visual differences occurred during aging, the colorimetric values of the same areas of the receipt measured before the aging treatment were also measured and the calculated differences in the colour (ΔE^*_{00}) caused by sunlight are presented in Figure 4.



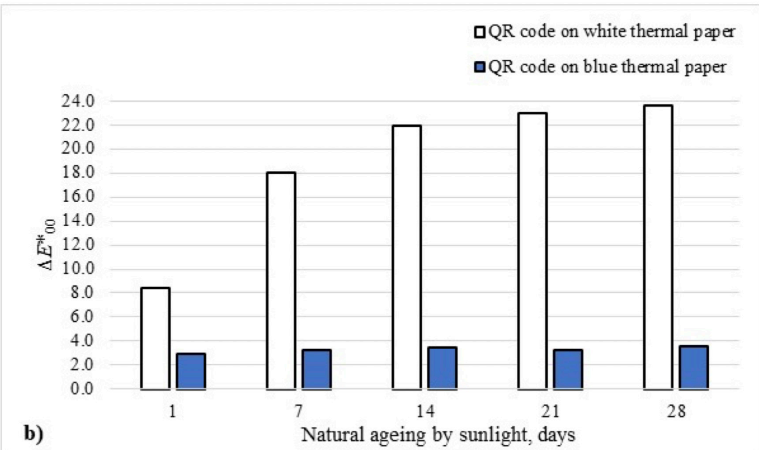


Fig 4. The influence of light on the stability of: a) thermal paper; b) receipt

Also, receipts on blue CRTP showed much better stability to sunlight (Figure 4b) than on white CRTP (Figure 4a). By comparing the light stability of the printed QR code on blue and white CRTP, it is evident that the duration of the sample exposure to sunlight has no effect on enhanced degradation. The change in colour of the QR code printed on blue CRTP has shown after the first 24 hours of exposure ($\Delta E^*_{00} = 3$) and was retained throughout all 28 days of aging, which was not the case with the QR code printed on white CRTP. In the first 24 hours, a QR code printed on white CRTP has shown a ΔE^*_{00} value of 8.4. Each hour of exposure has led to further degradation of the print, and after 672 hours of aging (28 days), the ΔE^*_{00} value has reached 23.66.

The test of the thermal paper's resistance to rubbing indicates that the white CRTP is more stable than the blue one. This can be related to the paper smoothness. Surprising was that the print itself on blue CRTP in any part of the receipt was more stable to rubbing than on white paper (Figure 5).

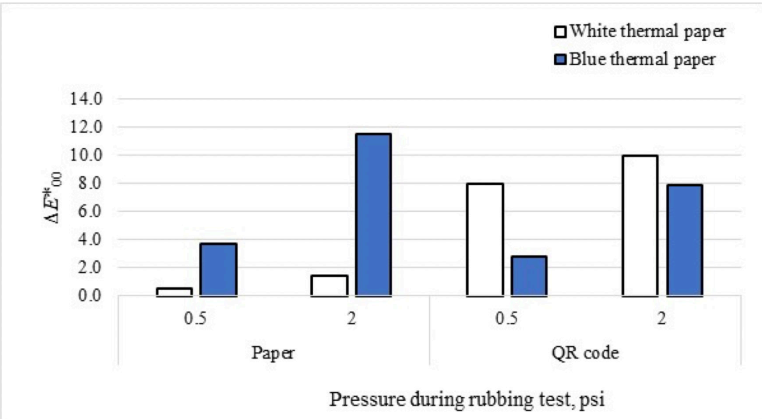


Fig 5. Changes in colour of cash register thermal paper after rubbing test

To additionally prove the mechanical stability of receipts printed on white and blue CRTP, the transfer of colour to the counter paper during rubbing (photocopy paper) was also analysed (Figure 6). It was noticed that the transfer of colour from both receipts is minimal and imperceptible, but white CRTP has showed slightly higher colour transfer compared to blue one.

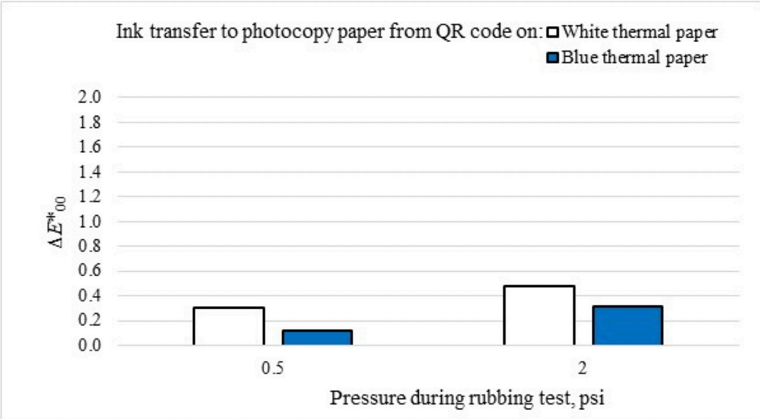


Fig 6. Change in colour of the counter paper during rubbing test

Conclusions

1. After contact with water and exposure to sunlight, the receipt on the white cash register thermal paper almost completely disappeared, while it was still present and in a good quality on the blue one.
2. Although white CRTP itself showed better resistance to rubbing than blue, receipts printed on blue thermal paper were more stable to rubbing and there was less colour transfer during rubbing than in the case of receipt on white CRTP.
3. According to the performed analysis in this study we can conclude that blue CRTP and receipt printed on it is more stable than on white CRTP.

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STUDY ON THE QUALITY OF REPRODUCTION OF GRAPHICAL LINEAR MICRO-IMAGES USING ELECTROPHOTOGRAPHIC PRINTING

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Abstract

Today's market of visual graphic communication includes many various advertising, publishing and packaging products printed on different materials. Many products are printed using conventional printing technologies such as offset printing or flexography, in addition to digital ones like Electrophotography and Ink Jet.

The graphic images on prints often contain extremely fine graphic details, such as micro-lines or micro-text elements, which are part of various identification, security markings, codes, etc. It is a very important task to optimally model these micro-images on printed graphic communication products at the design stage, in order to ensure their brightness, legibility and geometric dimensions meet the requirements, not only immediately after printing, but also, for example, after a certain period during the life cycle of the printed product after exposure to the sunlight spectrum, or to other mechanical or environmental effects.

This paper presents a methodology and results for the assessment of the quality of the reproduction of fine image details, i.e. the micro-lines of different widths arranged on the print in different directions. A specially developed original digital press quality control wedge with monochromatic micro-lines, microtext and screen dots bars of CMYK colours was applied to assess the accuracy of micro-image reproduction. In this part of the study, the wedge fields with positive micro-lines arranged in different directions individually and in groups were analysed. The width of the micro-lines was measured under the microscope to assess the accuracy of the dimensional reproduction and the deviations from the nominal value. To assess the influence of different parameters of the system "printing press-paper-inks" on the reproduction of image microelements, the prints for this part of the study were printed using electrophotographic printing techniques on different dry-toner printing presses on different types of paper.

The width and deviations of the micro-lines on the print were measured along the print direction, perpendicular and at 45˚ to the print direction.

Measurements of the reproduction accuracy of monochrome micro-line

images, printed on dry-toner electrophotographic presses, showed that the accuracy of micro-line reproduction depends not only on the printing system, its resolution and the characteristics of the paper, but also on the direction of the positioning of the micro-lines on the printed sheet.
The obtained results allow us to compare the capability of digital printing systems to reproduce linear micro-images on visual graphic communication products of any size and geometric orientation, to select optimal systems for printing specific products, and to model the layout of micro-images on products at the design stage, by assessing the orientation of the micro-images on the printed sheet.
Keywords: *Electrophotography, digital printing, control wedge, micro-lines, print quality.*

Introduction

In addition to offset and flexographic printing, Electrophotography and Inkjet digital printing technologies are often used for different reasons to print modern graphic communication products. As in all printing technologies, in addition to accurate colour rendering on print, there is also equally important quality of printing of thin micro details of the image. The quality of printing of the micro-images, the geometric definition, accuracy and legibility of their elements, including identification by automated techniques, depend on many parameters: the resolution (dpi) of the digital press, the properties of the printing materials, the composition and physical characteristics of the ink, etc.

Modern electrophotographic and Inkjet printing presses can be used to produce high-quality products. Although, for example, the quality parametres of offset printing are often higher (Yılmaz U. et al, 2021; Mai Ch., Hoang T., 2023), those two digital printing technologies can also be successfully used for medium or small runs of packaging, advertising publications or other high-quality products, as well as for prints with micro-images such as thin 0,05–0,2 mm monochrome micro-lines, micro-type, screen dots and other image details forming various code or other purpose micro-image systems on the print. These marks are often scanned by special automated devices, therefore, the accuracy of the reproduction of the micro-image details, their resolution, the homogeneity of the line and spacing widths, and the uniformity are very important. For example, micro QR code symbols, printed with low contrast, non-uniformity of disconnected dots or other defects, may not be readable by a scanner (ISO/IEC 18004:2015).

As different electrophotographic and Inkjet digital printing systems differ in their ability to precisely reproduce image micro-elements on the print, it is important not only to control the reproduction of these elements, but also to accurately model images with micro-lines or micro-type at the design stage, taking into account the ability of the printing systems to reproduce them. Currently, various digital print quality control wedges are used to ensure the reproduction accuracy of graphic micro-images, yet they lack information to allow the accuracy of reproduction of a wide range of micro-lines and various monochromatic micro-images to be monitored conveniently even under production conditions.

Predictable print quality issues have been discussed by various authors. For example, the Fogra Research Institute for Media Technologies (Kraushaar A., 2022) provides requirements and recommendations for data preparation and digital colour printing. When defining the requirements for a digital print, the following aspects are highlighted such as colour reproduction, detail sharpness and homogeneity of the printed production (A. Kraushaar, 2022, p. 70). Barcodes (1D) and matrix codes (2D) on a variety of papers and packaging materials are also often printed, for example, on Inkjet printing systems. The Fogra Barcode Test bar was developed for visual and metrological evaluation of barcodes (Fogra Research Project Barcode (11.004), 2021). Optimisation of the quality assessment process of barcodes printed using inks with magnetic properties, assessment of barcode line width, uniformity and edge irregularity, the accuracy of the reproduction of lines and intervals is important for accurate automated reading of barcode information (Havenko S. et al, 2020).

For the control of micro-images with details significantly finer than the lines in the barcodes in Inkjet systems, for example, a specific test-object has been proposed with micro-lines of different orientations and widths (Sysuev I. et al, 2019). This test-object also focuses on the orientation of the micro-lines to assess their reproduction on the print when using Inkjet printing presses.

The specifics of electrographic printing are fundamentally different from Inkjet. In terms of laser imaging technologies, the original control wedge was developed to assess the quality of reproduction of images on offset digital thermosensitive printing forms on Computer-to-Plate (CtP) systems with high 2400–3200 dpi resolution and above, including the possibility to assess function of modulation transfer (Sajek D., Valčiukas V., 2011; Sajek D., 2014; Sajek D., Valčiukas V., 2021). This control wedge was also used to control 0,01–0,15 mm micro-lines positioned in different directions, allowing to assess the micro-line reproduction inaccuracies over a wide range of dimensions as the laser image is formed parallel, perpendicular and at a 45˚angle to the direction of laser head movement.

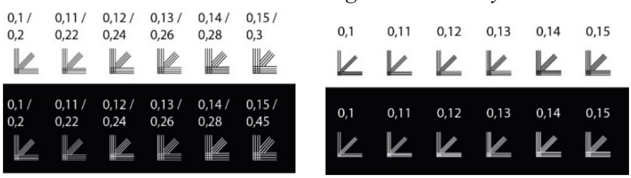
Methodology and equipment

The study aims to develop a universal control wedge, which can be used to control and pre-model the reproduction quality of thin linear micro-images over a wider range, printed by various digital printing techniques on different materials. In this part of the study, a control wedge will be used to control the quality of the reproduction of micro-lines on electrophotographic prints produced with dry inks.

This original control wedge was developed in Adobe Illustrator. It consists of monochromic micro-lines, micro-font and screen dots fields in CMYK colours, and other control elements. This part of the study deals with the control wedge part, which is used to control the accuracy of the reproduction of micro-lines.

The whole control wedge micro-line part consists of micro-lines ranging from 0,01 mm to 0,15 mm in width, varying in 0,01 mm intervals in the positive and negative fields aligned individually (Fig. 1) and in groups, respectively. Fragments of the control wedge (Fig. 2) show the micro-lines are aligned individually with double-width spacing (Fig. 2, a) and in groups with equal-width spacing (Fig. 2, b). The micro-lines are aligned parallel, perpendicular and at an angle of 45° to the print direction in the positive and negative fields of the wedge.

Fig. 1. The part of the control wedge for 0,01–0,15 mm width positive and negative micro-lines arranged individually



a *b*

Fig. 2. Fragments of the control wedge of 0,1–0,15 mm width positive and negative micro-lines a) arranged individually; b) in groups

The accuracy of the reproduction of micro-lines for the following systems "printing press-paper-ink" was assessed. The print tests were printed on electrophotographic presses *Xerox Versant 280 Press (Press 1)* and *Ricoh Pro C5200S* (*Press 2*) using dry ink (toner) at 1200 dpi and 2400 dpi resolution. The papers selected for the print run were Novatech Digital Silk (200 g/m^2) and Image Digicolor (70 g/m^2), which are often used in digital printing. Both types of paper have a relatively high surface smoothness: the measured R_a Novatech Digital Silk is 0,504 µm along to the direction, 0,589 µmin perpendicular the direction; Image Digicolor R_a is 0,497 µm along to the direction, 0,576 µm perpendicular the direction. Standard ink (black toner) for printing on *Xerox Versant* and *Ricoh Pro* printers was used.

The width of the micro-lines on the prints was measured using a digital microscope Dino Lite AM4013MT (Fig. 3).

Fig. 3. Digital microscope Dino Lite AM4013MT (magnification 10–70×, 200×)

5 prints were printed with the identical parametres on both types of paper. 1200 dpi resolution, 150 lpi and 200 lpi was used in *Press 1, whereas* 1200 and 2400 dpi resolution, and 200 lpi using Press 2. After selecting two prints without visual defects, the widths of the micro-lines were measured immediately after printing and deviations were determined. The remaining prints will be used in the next stage of the study to determine the level of environmental (lighting, humidity), temporal (ageing), mechanical (rubbing) effects and the variation in the colour properties of the prints and the dimensions of the micro-lines.

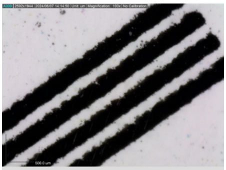
Micro-lines from 0,01 mm to 0,15 mm, aligned with the print direction (parallel) and perpendicular and at a 45˚ angle to the print direction, were assessed. The lines were measured with a *Dino Lite AM4013MT* microscope. The lines aligned individually with double-width spacing, and those aligned in groups with equal-width spacing, were measured by taking the lines from the middle of the group (Lines 2 and 3). The width of the lines was measured 5 times each, and the average was derived. Unstable, uneven and blurred lines without spacing, the width of which could not be assessed, were rejected as not being precisely reproduced on the print.

Results

The results of the micro-lines width measurements on the prints produced with *Press 1* showed that virtually stable reproduction of the micro-lines is possible only from 0,06 mm when the lines are aligned in groups with equal-width spacing and oriented to the print direction. When using 150 lpi, reproduction of micro-lines, is better, than using 200 lpi; it is evident especially on Novatech Digital, 200 g/m^2.

When micro-lines are aligned individually, using 1200 dpi resolution and 200 lpi, reproduction of 0,04 mm micro-lines is reasonably good. The reproduction of the 0,08 mm micro-lines and above can be considered stable, but the accuracy of the reproduction depends on the position and the resolution; the gain in the width is significant, amounting to between 20 % to 50 % on average. As the width of the micro-line increases, the relative gain in its width decreases (Table 1, Fig. 4).

a



b

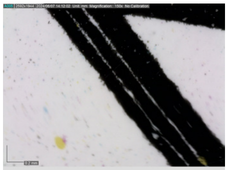
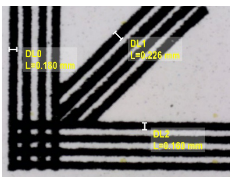


Fig.4.Microphotographs of 0,08 mm micro-lines: a) separate line; b) line in group. Press 1 print, 1200 dpi, 150 lpi, Image Digicolor 70 g/m^2

The results of the micro-lines measurement on the prints produced with *Press 2* show that stable micro-line reproduction in this system starts at 0,08–0,1 mm when the micro-lines are aligned individually with double-width spacing, but when the micro-lines are aligned individually with double-width spacing, 0,08–0,1 mm width micro-lines are only reproduced at 1200 dpi resolution (200 lpi); when printing at 2400 dpi resolution (200 lpi), only a stable reproduction of 0,12–0,15 mm width of these micro-lines can be expected, but with a significant width gain of approximately 80% (*Table 2, Fig. 5*).

a



b

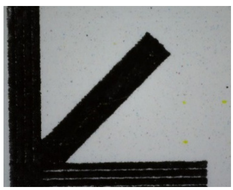


Fig.5. Microphotographs of 0,1 mm micro-lines: a) separate line; b) line in group; Press 2 print, 1200 dpi, 200 lpi, Novatech Digital 200 g/m^2

Table 1. Results of micro-lines width measurement. Press 1

No.	Paper, g/m^2,	dpi/ lpi	Approx. width of micro-line, mm (in file)								Position to print direction	Gap width, ×
			0,01	0,04	0,05	0,06	0,08	0,1	0,12	0,15	Per ‖ Par ═	×1, 2
			Approx. width of micro-line, mm (print)									
1	Novatech Digital, 200	1200/200	–	–	–	n	0,12	0,12	0,15	0,17	Per ‖	×1
			–	–	–	0,10	0,12	0,13	0,15	0,18	Par ═	×1
2	Novatech Digital, 200	1200/200	–	0,06	0,08	0,10	0,13	0,14	0,16	0,20	Per ‖	×2
			–	0,06	0,09	0,10	0,12	0,13	0,15	0,18	Par ═	×2
3	Novatech Digital, 200	1200/150	–	–	n	n	0,12	0,13	0,16	0,19	Per ‖	×1
			–	0,06	0,08	0,10	0,13	0,14	0,16	0,20	Par ═	×1
4	Novatech Digital, 200	1200/150	–	–	0.07	0.08	0,12	0,13	0,16	0,19	Per ‖	×2
			–	–	0.08	0.08	0.14	0.12	0,16	0.20	Par ═	×2
5	Image Digicolor 70	1200/200	–	–	–	–	0.13	0,12	0,15	0,19	Per ‖	×1
			–	–	0.08	0.08	0.14	0.12	0,16	0.20	Par ═	×1
6	Image Digicolor 70	1200/200	-	-	-	-	0.13	0,13	0,15	0,19	Per ‖	×2
			-	-	0.08	0.08	0.14	0.12	0,16	0.20	Par ═	×2
7	Image Digicolor 70	1200/150	-	-	-	-	0.12	0,12	0,14	0,19	Per ‖	×1
			-	-	-	-	n	0.13	0.16	0.20	Par ═	×1
8	Image Digicolor 70	1200/150	-	-	-	0.10	0.12	0.13	0.16	0.20	Per ‖	×2
			-	-	n	0,11	0.14	0.14	0.17	0.21	Par ═	×2

n – impossible to measure

Table 2. Results of micro-lines width measurement. Press 2

No.	Paper, g/m^2,	dpi/lpi	Approx. width of micro–line, mm (file)								Position to print direction	Gap width, ×
			0,01	0,04	0,05	0,06	0,08	0,1	0,12	0,15	Per‖Par =	×1, 2
			Approx. width of micro–line, mm (print)									
1	Novatech Digital, 200	1200/200	–	–	–	–	0.11	0.14	0.15	0.20	Per‖	×1
			–	–	–	–	0.11	0.15	0.16	0.20	Par =	×1
2	Novatech Digital, 200	1200/200	–	–	0.10	0,10	0.12	0.14	0.17	0.20	Per‖	×2
			–	n	0.11	0.10	0.14	0.15	0.18	0.21	Par =	×2
3	Novatech Digital, 200	2400/200	–	–	–	–	n	n	0.22	0.24	Per‖	×1
			–	–	–	–	n	n	0.23	0.24	Par =	×1
4	Novatech Digital, 200	2400/200	–	–	–	n	0.13	0.16	0.18	0.22	Per‖	×2
			–	–	–	n	0.14	0.20	0.21	0.25	Par =	×2

n – impossible to measure

For *Press 1*, the micro-lines aligned individually parallel to the print direction was found to have a greater width gain than the lines aligned perpendicular to the print direction (Fig. 6, 7). The change in line widths depends on the paper, in particular for micro-lines of 0,04–0,08 mm width, as they are more unstable when they are printed on a thinner paper such as Image Digicolor 70 (Fig. 7).

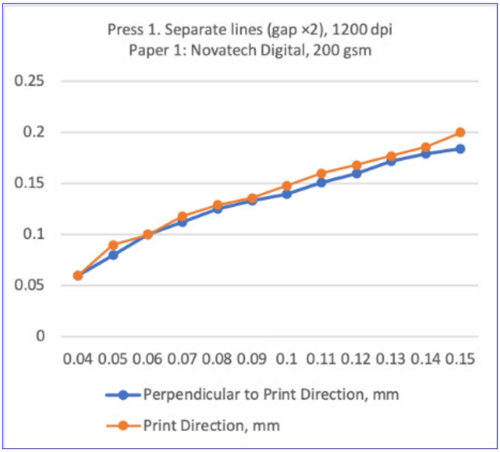


Fig. 6. Micro-lines printed on Press 1, Novatech Digital (200 gsm)

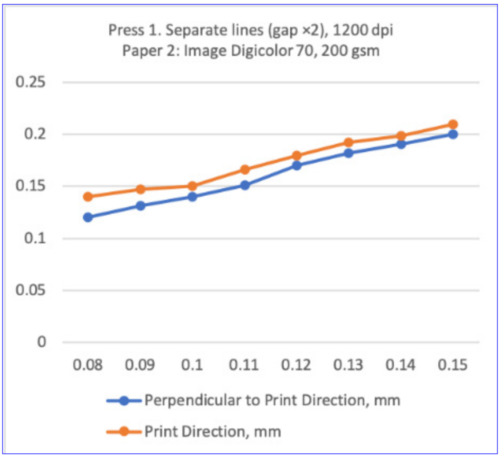


Fig. 7. Micro-lines printed on Press 1, Image Digicolor (70 gsm)

For *Press 2* it was found out, that when using 1200 dpi, thin micro-lines (0,06–0,1 mm) are reproduced better than when using 2400 dpi; stable reproduction can be achieved from 0,08 mm for lines in groups, and from 0,06 mm – for separate lines.

When using 2400 dpi, the reproduction of thin micro-lines (0,08–0,1 mm) is worse, especially for lines in groups – even in a group of 01 mm width lines, the small gaps begin to appear when the micro-lines are oriented perpendicular to print direction; when parallel– the lines merge. The micro-lines width gain for 2400 dpi is more significant than using 1200 dpi, for example, separate 0,1 mm micro-lines oriented to the print direction reproduced as 0,2 mm; separate 0,15 mm micro-lines, orientated to the print direction, reproduced as 0,25 mm – the gain is up to 100 %, whereas when using 1200 dpi resolution, accordingly; separate 0,1 mm width micro-lines oriented to the print direction, reproduced as 0,15 mm (50 % gain); separate 0,15 mm width micro-lines oriented to the print direction, reproduced as 0,21 mm. The width gain of all the micro-lines (in groups and separately) is more significant when printed on 2400 dpi, especially when the lines are directed to the print (Table 2, Fig. 8, 9).

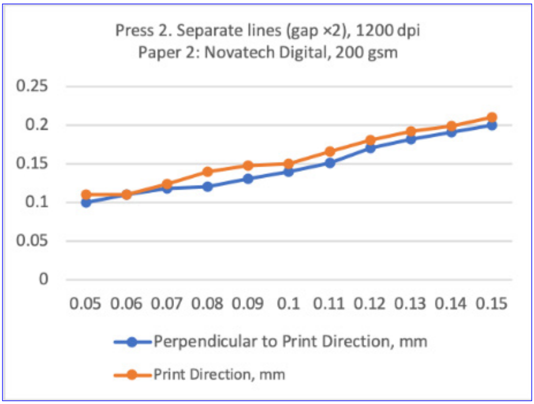


Fig. 8. Micro-lines printed on Press 2, 1200 dpi

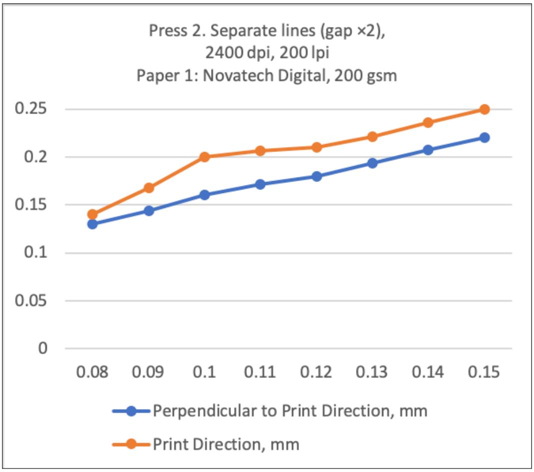


Fig. 9. Micro-lines printed on 2400 dpi

Conclusions

The study showed that the original control wedge with a large range of micro-lines with different widths and arrangements can be successfully used to assess the quality of digital prints with linear micro-images.

Comparison of prints produced with two electrophotographic printing systems working with dry inks (toner), and measurements of the reproduction accuracy of monochrome micro-line images showed, that the accuracy of micro-line reproduction depends not only on the printing system, its resolution and the characteristics of the paper, but also on the direction of the positioning of the micro-lines on the printing sheet. The composition and properties of the inks, as well as the type of paper and the surface morphology, can also influence the accuracy of the reproduction of micro-images, therefore these factors will be assessed in further study.

The results allow a comparison of the capabilities of electrophotographic digital printing systems to reproduce linear micro-images on visual graphic communication products of any size and geometric orientation, to select optimal systems for printing and to model the layout of micro-images at the design stage, by assessing the orientation of the micro-images on the printed sheet.

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CRITERIA FOR SELECTING ARTIFICIAL INTELLIGENCE TOOLS

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Abstract
Artificial Intelligence (AI) represents a transformative force across numerous sectors, from healthcare and finance to automotive and public services. The selection and deployment of AI tools are critical to leveraging this technology's potential while adhering to ethical standards, regulatory compliance, and ensuring societal benefit. The European Union (EU) has been at the forefront of establishing frameworks and criteria to guide the development, deployment, and selection of AI systems to foster innovation while protecting citizens' rights and societal values. The EU's proactive stance in establishing these criteria aims to balance innovation with ethical considerations and societal welfare, setting a benchmark for responsible AI development and deployment globally. The aim of the article is to present general criteria for the selection of artificial intelligence tools, as well as those specific to the field of publishing. The research was carried out based on the analysis of scientific and other sources. The results of the study can be useful for organizations and individuals that must be interested in selecting and using the right AI tools.
Keywords: *artificial intelligence, selection criteria, EU regulations, publishing.*

Introduction

The rapid development of artificial intelligence (AI) in various areas of professional activity and life makes it possible to achieve the required results faster, easier and more innovatively, but it also obliges us to use AI responsibly. Defining AI is sometimes problematic because AI mimics human intelligence and it is conceivable that AI has human-like abilities (Devi, Manjula, Pattewar 2023). Scientists identify types of AI based on levels of task performance and say that AI recently lacks the ability to make decisions and reason like a human. AI is like a collection of certain algorithms and data, it is also called a branch of science (Tarasevičienė, Šutienė 2022). It is a combination of tools and processes that create results according to the needs of users (Veale, Matus, Gorwa 2023). Artificial intelligence helps to efficiently perform functions that require analysis, implementation of ideas and solutions, and competitive advantage (Mhlanga 2023). Currently, there is no unified definition of AI, so it is worth referring to the definition provided by the expert group appointed by the European Commission: “Artificial intelligence (AI) refers to systems that display intelligent behaviour by analysing their environment and taking actions – with some degree of autonomy – to achieve specific goals. AI-based systems can be purely software-based, acting in the virtual world (e.g. voice assistants, image analysis software, search engines, speech and face recognition systems) or AI can be embedded in hardware devices (e.g. advanced robots, autonomous cars, drones or Internet of Things applications).” (High-level expert group on artificial intelligence, 2019a).

It is extremely important to respond to the development of artificial intelligence, the tools being created, their functions and processes, to follow reliable information and to adapt it to the expected needs. Artificial intelligence tools create opportunities for users to use chatbots, create texts, videos, photos and music, plan communication campaigns, predict results, perform data searches, and implement technical processes. In the long run, society will adapt to changing personal skills, embrace new challenges, adopt artificial intelligence in processes, and make greater use of the aforementioned functions. A study by the International Monetary Fund (2024) revealed that artificial intelligence could affect 60 percent of jobs, optimize work, and most of all improve the provision of services in the field of health and education. Advanced economies should focus on innovation and integration of artificial intelligence when developing regulatory frameworks for the use of AI. There are many aspects to consider when using artificial intelligence, including legal, ethical and social aspects.

As the availability and use of AI tools increase, legal and ethical issues may arise, making it critical to select and use appropriate and reliable AI systems and tools. The criteria for the selection of artificial intelligence systems and tools must be compatible with the country’s and European Union’s regulation in the field of AI, as well as meet the requirements of the specific field and other important aspects. The purpose of the article is to present general criteria for the selection of artificial intelligence tools, as well as those specific to the field of publishing. The research was carried out based on the analysis of scientific and other sources.

Methodology and equipment

The selection criteria are applied in various fields. “A criterion is a sign, a rule according to which something is evaluated, determined, classified” (Visuotinė lietuvių enciklopedija 2024). Selection criteria are rules or guidelines used to select the most appropriate option from a group of alternatives. For example, science selection criteria include various aspects necessary for effective dissemination and progress (Reyes, Moraga 2020). In the field of journal selection, publication quality criteria are very important for the success of publishing and for researchers due to the evaluation of the dissemination of results (Šarlauskiene, Šarlauskas 2018). Selection criteria can be grouped by importance using a decision matrix where a list of choices is evaluated and prioritized. First, a list of weighted priorities is created and each option is evaluated against those priorities (Tague 2023). Lists of criteria and their priorities can be compiled by professionals or expert groups in the analysed field, and the help of AI tools can also be used. In this study, the list of criteria for the selection of artificial intelligence tools is compiled based on the analysis of scientific and other sources, giving priority to the regulation of the European Union in the field of artificial intelligence and aspects of the publishing field.

Presentation of research results

The selection criteria for artificial intelligence according to EU regulations are based on a tiered compliance framework that categorizes AI systems into different risk levels. The EU Artificial Intelligence Act (2024) defines four levels of risk for AI systems: unacceptable, high, limited, and minimal or no risk:

- Unacceptable Risk: AI systems posing unacceptable risks, such as those threatening people's safety, livelihood, and rights, are prohibited.
- High-Risk: AI systems falling into the high-risk category, used in critical infrastructure or law enforcement, face strict requirements. These requirements include aspects like risk assessment, data quality, documentation, transparency, human oversight, and accuracy.
- Limited Risk: AI systems posing limited risks, such as chatbots, are subject to transparency obligations to ensure users are aware that they are interacting with AI and not humans.
- Minimal or No Risk: AI systems with minimal risk, like games and spam filters, can be used without stringent regulatory requirements.

These risk levels determine the compliance obligations for developers and deployers of AI systems, with the level of obligations varying based on the risk posed by the AI system to people's safety, security, or fundamental rights. The EU AI Act aims to ensure the trustworthy and responsible use of AI systems by unifying regulations across the EU Member States and covering all AI systems impacting people in the EU, regardless of where they are developed or deployed.

The High-Level Expert Group on AI (2019b) presented *Ethics Guidelines for Trustworthy Artificial Intelligence*. According to the Guidelines, trustworthy AI should be not only lawful but also ethical and robust. The Guidelines put forward a set of 7 key requirements that AI systems should meet to be deemed trustworthy:

1. Human agency and oversight: AI systems should empower human beings, allowing them to make informed decisions and fostering their fundamental rights;
2. Technical Robustness and safety: AI systems need to be resilient and secure;
3. Privacy and data governance;
4. Transparency: the data, system and AI business models should be transparent;
5. Diversity, non-discrimination and fairness;
6. Societal and environmental well-being: AI systems should benefit all human beings, including future generations;
7. Accountability: Mechanisms should be put in place to ensure responsibility and accountability for AI systems and their outcomes.

For the practical application of these criteria for the selection of AI tools or systems, it has been developed *Assessment List for Trustworthy AI (*High-level expert group on artificial intelligence 2020). This list is intended for self-evaluation purposes.

It is important to consider all of the 7 aspects, but it is necessary to analyze and invest in data protection and policies that specify how data is collected, for what purposes and how it is stored. According to Felzmann et al. (2020), attention to data protection becomes one of the most relevant aspects when choosing to use artificial intelligence, since new tools appear every day, supply is high and demand is increasing, it is important to remain critical and assess the risks. This is one of the reasons why it is important to select AI tools to protect the data you provide. Thousands of people around the world are affected by the loss of sensitive personal data. Data leaks affect companies' reputations and finances, and may lead to legal problems (Kaur, Uslu, and Durresi 2021). Although an individual cannot always ensure the security of his data and ensure that the data stored in the company will be safe, when choosing artificial intelligence tools, it is possible to conduct an analysis, learn more about a specific tool, its reputation, accountability, crisis management, etc. Defining AI selection criteria can help avoid risks and frustrations.

EU regulation of the use of AI covers all areas of activity and can help solve the problems of evaluation and selection of AI tools. However, the criteria for selecting AI tools for individual areas of activity, which are specific to a specific area, may also be important.

Ethical aspects of AI in publishing encompass concerns such as plagiarism, authorship attribution, content originality, and maintenance of research integrity. AI tools like ChatGPT can aid in manuscript preparation by saving time, generating accurate text, and ensuring proper citations. However, there are risks of inaccuracies, lack of originality, and questions regarding authorship when AI is heavily involved in writing (Kurian et al, 2023; Dupps 2023; Smeds et al, 2023; Pividori & Greene, 2023). Guidelines from publishers and organizations emphasize the responsibility of authors to oversee AI-generated content, disclose AI use, and maintain research integrity. While AI can enhance research productivity, it should not replace human critical thinking and expertise to uphold the quality and ethical standards of academic publishing. Vigilance and ethical awareness are crucial to harness the benefits of AI in publishing while mitigating potential risks.

Since EU documents do not provide specific recommendations for the use of artificial intelligence tools in publishing, most publishers have provided their recommendations and guidelines. Authorship issues received the most attention. The research shows that even 98 percent of Journals have banned generative AI as an author (Pongrac, 2024). COPE (Committee on Publication Ethics) also states that AI tools cannot be listed as authors of an article (https://publicationethics.org/cope-position-statements/ai-author).

Other potential risks of using AI in publishing, as in other fields, can include AI integration with existing systems, cost of AI implementation, lack of skilled talent in the publishing industry, the publishing industry's resistance to change. Integrating AI systems with existing workflows, processes, and technology can be challenging, requiring significant resources, technical expertise, and training for employees.

The described ethical and other aspects of AI tools can serve as selection criteria for AI tools, as they are relevant for the selection and use of appropriate AI tools in publishing. Ranking these tools according to their importance or making a list of their priorities would not be appropriate in this case, because both the general EU requirements and the relevant and independent aspects of publishing are important.

Conclusions

- The research results showed that the list of basic and general selection criteria for artificial intelligence tools can be compiled according to the EU AI Act, which divides artificial intelligence systems into different risk levels, and 7 requirements of the Ethics Guidelines for Trusted Artificial Intelligence.

- In addition to the general criteria, the selection criteria of AI tools for specific fields of activity are also important. Although scientific sources analyze individual aspects of the ethics, selection and use of AI tools, the most common ones can be distinguished. Ethical aspects of AI in publishing encompass concerns such as plagiarism, authorship attribution, content originality, and maintaining research integrity. Integrating AI with existing systems, the cost of implementing AI, the lack of skilled talent in the publishing industry, and the publishing industry's resistance to change are other potential risks of using AI in publishing that need to be considered when selecting AI tools.
- With the rapid development of AI and the active debate about the ethical and appropriate use of AI tools, more detailed and specific information will emerge in the future for various fields and also for publishing.

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STUDY OF THE MECHANICAL PROPERTIES OF CARDBOARD WITH BARRIER PROPERTIES

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Abstract
The aim of this study is to test and compare the mechanical properties of the cardboard selected for the tests and to determine the best type of material. As cardboard is used in a wide range of industries for the packaging of goods, it is important to determine which of the types of cardboard tested is the most resistant to wear and the least deformable under changing environmental conditions. It is also important to compare and identify what improvements could be made to existing materials to make the board durable and environmentally friendly. To conduct the experiment of this study, four types of cardboard with barrier properties were used. For all the tests sample groups of different cardboards with different barrier properties were prepared and the specimens were stored and acclimatised under the same conditions before the tests. Specific software and devices were used to determine the final results. Selected types of tests were chosen to compare the types of cardboard as they are close to the real-life use of the packaging. After obtaining results of selected tests, compared values have shown that there were no significant changes, but there were some differences in the strength properties, which could be mainly due to the different mechanical properties of each type of paperboard. As a result, one type of paperboard was superior in both resistance and wetting tests. To conclude, this study, which was carried out to compare the strength properties of four different types of cardboard and their behaviour caused by changed surroundings demonstrates that all the types of tested cardboards are proper for use but need to be protected from direct wetting or wearing and tearing. Furthermore, this study helped to obtain new directions and ideas on how cardboard could be improved and made an even more resilient but environmentally friendly material and how it could be improved and applied in industrial companies in the future.
Keywords: *cardboard packages, cardboard improvements, barrier properties*

Introduction

In our fast-paced environment where we are used to get all needed goods immediately, packages represent and service a very important role. Usually, different kind of packaging is met in almost every area of food industry, pharmaceuticals or hygiene products, non the less including all the huge variety of items used every day that come in packaged. The package itself not only serves as a protection of a product, but may be used as a way of delivering additional information or advertise brand or other products (Gunaratne, N. M. et al., 2019). Packages are used as primary or secondary depending on the packaged product that is why the chosen materials shall be safe, not to contaminate the product, be sustainable and recyclable, easy producible and durable for the required period (Deshwal, G.K. et al., 2019). It is important not only to pack a product, but make it as accessible as possible, e. g. for people with visual impairments. Braille is one way of presenting the most important information, but it is very important to choose right materials and printing techniques (in this study, embossed Braille was used) to ensure minimal damage for written text that might be caused by environment factors (Havenko, S. et al., 2016). Furthermore, packaging should be well thought through and made as environmentally friendly as possible. According to Eurostats and comparing numbers of years 2021 and 2020, plastic packaging waste generation increased by 4 % per capita followed by an increased recycling rate by 9.5% (Eurostat, 2023). The rising numbers of recycled materials are encouraging but the part, which is left, usually is buried or burnt (Cheng, H. et al., 2021). That is a very important reason why materials, which incorporate great qualities and offer additional moisture and grease barrier keeping recyclability option instead of additional layer of different material, could be explored and adapted even more. For this study cardboard with additional barrier properties (MM Group, 2014) and Braille printed on top was chosen with an aim of checking cardboards' reaction to environmental changes and Braille resistance to some of possible damaging factors.

Methodology and equipment

For this study of cardboards and their properties, four types of cardboards suitable for contact with food where chosen with different grease and moisture barrier properties. The materials that were chosen are listed: 'Accurate', 'Accurate Freeze', 'Accurate Freeze Grease KIT 7-9', 'Accurate Freeze Grease KIT 9-11'. These cardboards were prepared in the production line, so each sample was already enhanced with a short Braille lettering executed by embossing it on each type of cardboard sheet. The main characteristics of all used cardboards are summarized and presented in Table 1 below.

Table 1. Characteristics of four types of cardboard with barrier properties

Cardboard type	Accurate	Accurate Freeze	Accurate Freeze Grease KIT 7-9	Accurate Freeze Grease KIT 9-11
Grammage g/m^2	305 +/- 2%	305 +/- 2%	305 +/- 2%	305 +/- 2%
Thickness, µm	520 +/- 5%	520 +/- 5%	520 +/- 5%	520 +/- 5%
Gloss 75°, %	> 45	> 45	> 45	> 45
Smoothness top, µm	1,0	1,0	1,0	1,0
Brightness top (% Elrepho)	90 %	90 %	90 %	90 %
Stiffness L&W, mNm	29,8	29,8	29,8	29,8
Additional properties	Cardboard with a high visual impression, neutral in odour and taste.	With additional moisture barrier (freeze barrier) and resistant to temperature fluctuations	With combined moisture barrier and grease barrier (freeze-grease barrier)	With combined moisture barrier and grease barrier (freeze-grease barrier)
Applications	Cosmetics and personal care, Pharma and health care, dry, fast food	Fruit and vegetable, Frozen food, Chocolate and confectionary, Fast food	Dry food, Frozen food, Chocolate and confectionary, Fast food	Dry food, Frozen food, Chocolate and confectionary, Fast food

To make sure, that every cardboard is prepared for the testing in the same way, all sheets were kept in the same environment for a few days. The conditions for preparing the specimens were room temperature of around 21±1 ºC and moisture 50±1 %. Samples of different types of cardboard were prepared and tested using Braille dots checking device and software to measure the parameters of Braille dots for the first test and pocket goniometer to measure the contact angle between the surfaces of the samples and water droplets for the second test.

For the first test specimens were prepared using the part of each cardboard with embossed text. Six samples were cut out of each cardboard type making sure that each specimen includes Braille lettering. All Braille dots on the samples were measured using ‘Brai3’ device and ‘Peret’ software. As Braille is embossed as a three dots marking in the column, this device takes an image of every three dots and analyses their characteristics. Using the ‘Peret’ software each dot can be selected and according to chosen settings for measuring and analyzing, information of every dot is shown in the image. The gained information is height of selected dot, base diameter and information if size of a dot passes the normal values based on selected settings. An example of measured dot is given in Fig 1.

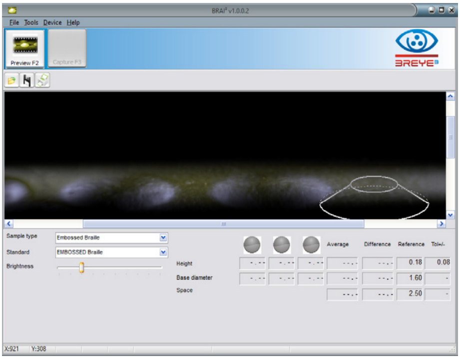
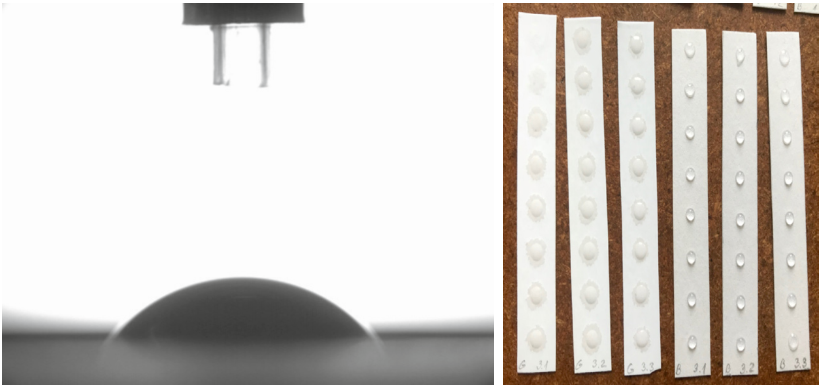


Fig 1. Example of Braille dot measuring and image on the screen

All dots on the specimens were measured and thirty dots were marked specifically on the cardboard for further investigation. The measurements of all dots were saved for analysis. To check if environmental changes makes an impact on cardboard surface and effects Braille dots, all prepared samples were stored in a freezer in a surrounding temperature of around –18±1 ºC and moisture of 68±2 % for 60 days. The samples were visually inspected regularly to ensure no changes in appearance. After 60 days the specimens were taken out and all dots that were marked before were measured again. Obtained results were compared to the ones received before changing the environment of samples storage.

For the second test, wetting angle test, specimens were prepared using the same sheets of cardboard that were used for sampling in the first test. Six sample strips of size 100x15 mm were cut out of every type of cardboard and marked accordingly. For this test three strips were used for each side of cardboard. This test was chosen to identify and monitor the differences between both sides of cardboard with barrier properties by investigating the contact angle of each side. To perform this test ‘The Pocket Goniometer PG2’ device for capturing and measuring the droplets and ‘PG program 3.1’ software for evaluating were used. The captured image of droplet and image of tested samples are presented in Fig. 2.



a *b*

Fig 2. Image of droplet captured using goniometer (a) and example of tested samples (b)

Using distilled water and device, eight droplets were dripped on each sample and measured. The measurements of each droplet were taken after dripping the droplet and letting it settle for a few seconds; after each drip the photo using goniometer was taken and data such as contact angle, base diameter, volume and height was collected. After measuring all samples, collected data was used to compare results between both sides and all used types of cardboard.

Presentation of research results

After the first test samples of cardboard with Braille dots were visually evaluated and no impact or change of form was noticed, measurement results of Braille dots on ‘Accurate’, ‘Accurate Freeze’, ‘Accurate Freeze Grease KIT 7-9’, ‘Accurate Freeze Grease KIT 9-11’ cardboards with different barrier properties were compared to the previous results of the same dots and average values confirmed minimal changes. The compared average results are displayed in Figures 3 and 4 below, showcasing minor changes in dot height and base diameter.

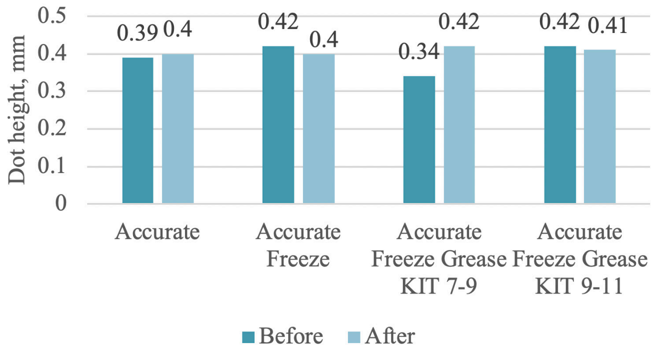


Fig 3. The changes of Braille dot height

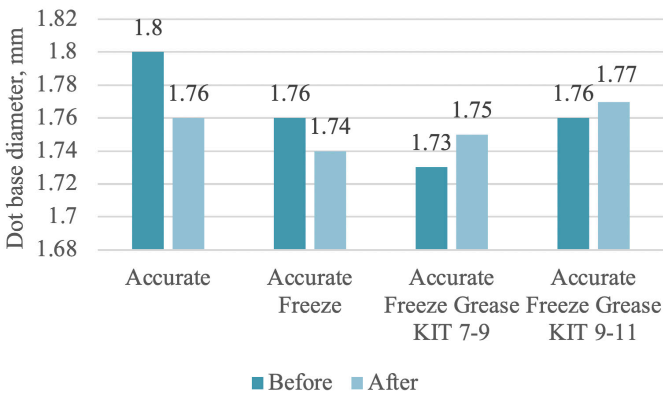


Fig 4. The changes of Braille dot base diameter

The changed conditions of samples storage have not made any major impact on Braille dots and it is possible to consider that barrier properties made an impact on preserving cardboard and Braille dots in the same state. Results demonstrate minor changes in measurements, but these changes have no major impact on dots measurements that would deviate from the standard dimensions and could reduce the possibility to read the embossed text.

Taking into consideration results of the wetting angle test, the measured values have shown that the reverse side of the cardboard tends to absorb fewer liquids than the upper side (Fig. 5).

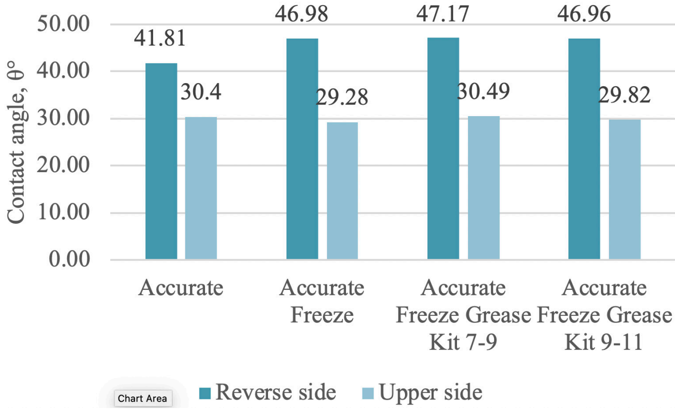


Fig 5. The compared contact angle of both cardboard sides

According to the results, the best performance on not-absorbing liquid was shown by 'Accurate Freeze Grease KIT 7-9' with a contact angle of 30.49 º on the upper side and 47.17 º on the reverse side. Cardboard 'Accurate', which has the lowest barrier properties according to the producer listed specifics, demonstrated better results on the upper side compared to moisture-resistant and grease-proof 'Accurate Freeze' and 'Accurate Freeze Grease 9-11' cardboards even if the difference is not major. On the other hand, results of the reverse side measured values have shown that 'Accurate' has the greatest absorbing capacity from all four tested cardboards.

Conclusions

- This study was carried out to check the properties and possible changes of four different types of cardboard designed with different levels of moisture and grease barrier properties and their behaviour caused by changed keeping environment. The results of test of Braille dots shows that cardboard with additional barrier properties manages to stay in the same state keeping the dimensions and visual appearance the same.
- Braille dots maintained almost the same dimensions after exposing the cardboard to freezing temperatures and moisture (an average change of the height of Braille dot was 0.03 and of base diameter 0.02 mm). Therefore, it follows that cardboard might be used for various food products and pharmaceutical packages and environmental changes should not impact suitability.

- The contact angle test has shown that upper side of all four cardboards is likely to absorb liquid almost 1.5 times more than the reverse side (the least absorbing 'Accurate Freeze Grease Kit 7-9' demonstrated results of 30.49 º on upper side and 47.17 º on reverse side) and even to change the cardboard look after applying water. This means that cardboard packages with barrier properties should be kept away from the direct contact with liquids.

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