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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).

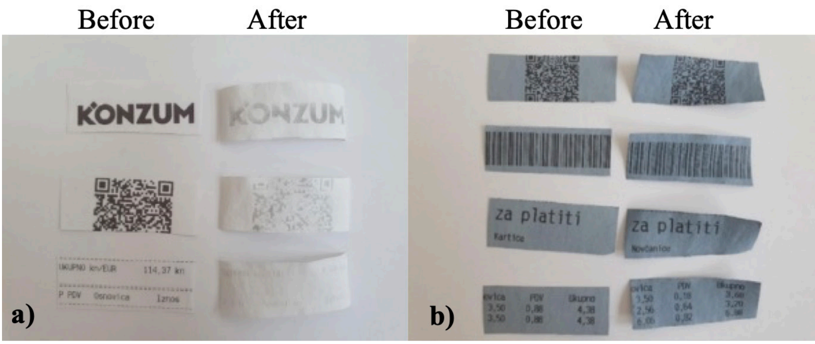

Fig 1. Pictures of receipt samples before and after treatment with distilled water: a) white CRTP; b) blue CRTP

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}.

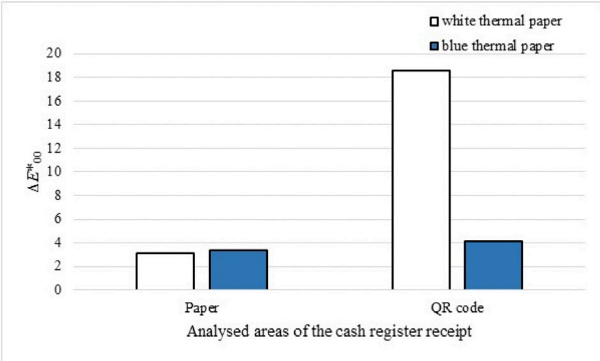

Fig 2. The influence of distilled water on the chemical stability of the cash register receipt

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).

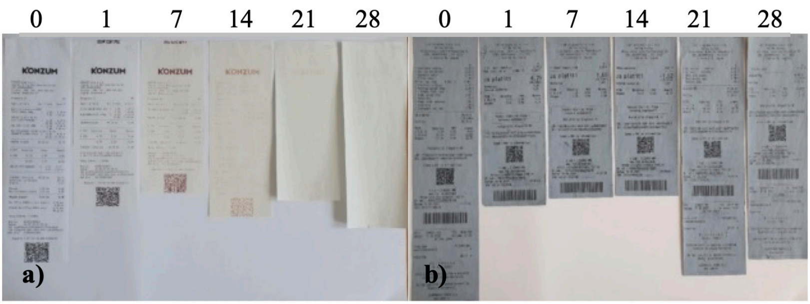

Fig 3. Pictures of receipt samples before and after treatment with sunlight: a) white CRTP; b) blue CRTP

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.

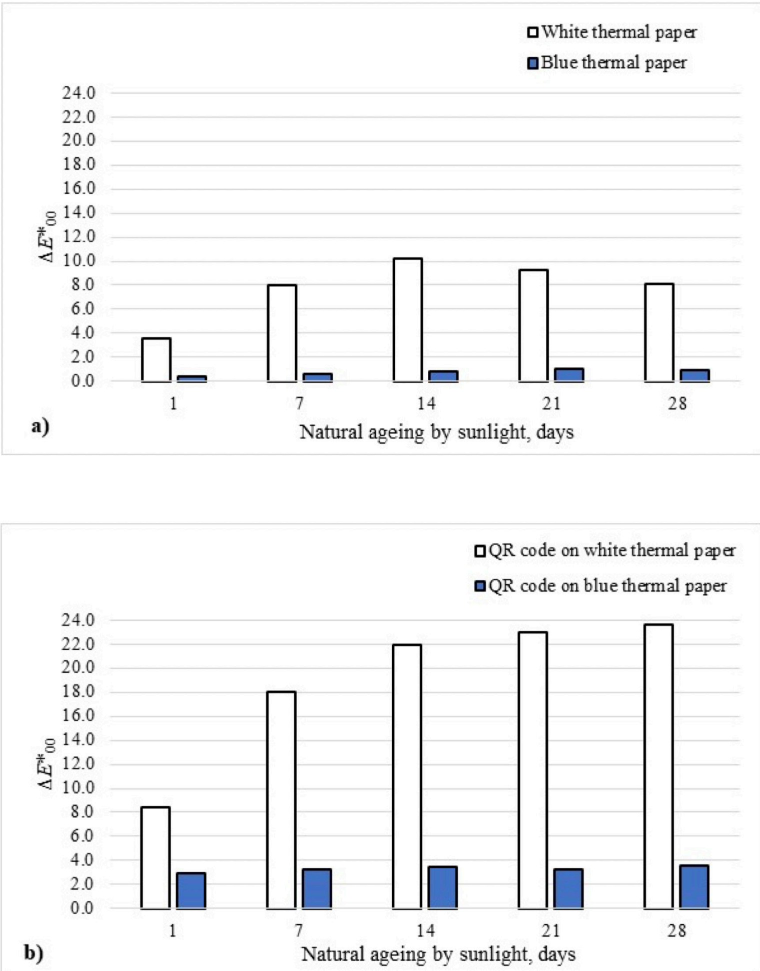

Fig 4. The influence of light on the stability of: a) thermal paper; b) receipt

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).

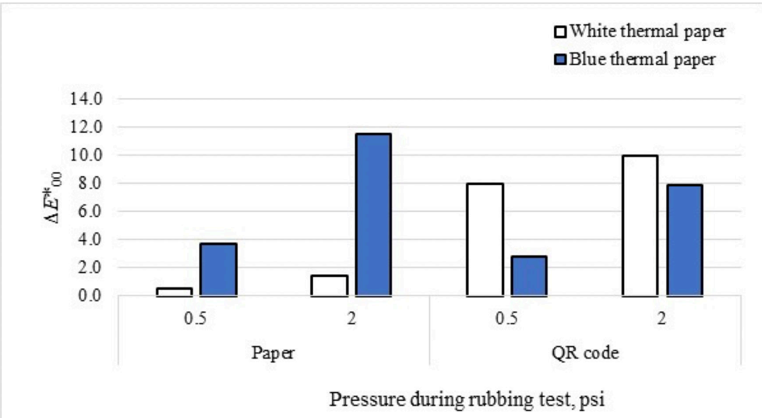

Fig 5. Changes in colour of cash register thermal paper after rubbing test

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.

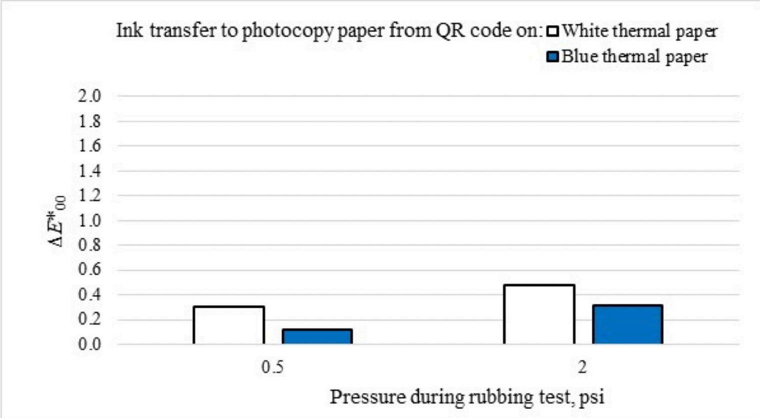

Fig 6. Change in colour of the counter paper during rubbing test

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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