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# Analysis of the Parameters Determining the Effect of Coated and Uncoated Papers on Print Quality

## Kaplanmış ve Kaplanmamış Kağıtların Baskı Kalitesine Etkisini Belirleyen Parametrelerin Analizi

Yasemin SESLİ*, Pelin HAYTA**, Ahmet AKGÜL***, Mehmet OKTAV****

*Dr. Öğretim Üyesi, Marmara Üniversitesi, yasemin.sesli@marmara.edu.tr, ORCID: 0000-0002-1238-9071
**Dr. Öğretim Üyesi, Sinop Üniversitesi, phayta@sinop.edu.tr, ORCID: 0000-0003-1613-0785
***Doç. Dr., Marmara Üniversitesi, ahmetakgul@marmara.edu.tr, ORCID: 0000-0001-8726-4727
****Prof. Dr., Marmara Üniversitesi, moktav@marmara.edu.tr, ORCID: 0000-0002-9872-4802

**Abstract**

Both paper and ink are the two main raw materials in the manufacture of printed materials. The visual quality of the printed product is very important. Printing an image on paper with ink in high resolution is dependent on the quality of the interfacial relationship between paper and ink. Newsprint, book paper, and pure cellulose-based high-grade paper pulp where the mechanical wood pulp is intensively utilized have porous structures. Coldset offset printing is used for printing on these papers. The coldset offset printing is a printing process where drying occurs late by evaporation of the liquid portion of the ink and absorption into the paper. The ink can sometimes take several days to dry completely (solidify). During this drying process, the ink penetrates the cellulose capillaries in the paper in the vertical direction and behaves the same in the horizontal direction. The dot diameter, which mechanically grows due to the printing pressure (dot gain), grows even larger by spontaneous micro-steps during the drying process. It tends to cross to the back surface of the paper in a vertical direction. For this reason, the paper-ink interfacial behavior is a critical parameter that should be maintained under control as much as possible. The rough surface, porous structure and humidity of the paper, the viscosity and amount of ink printed on the paper surface, the printing pressure at the NIP point, and the physical conditions of the printing room are influential in this interfacial relationship.

In this study, the factors that affect the image quality in printing on uncoated and coated papers were investigated by test printing. The CMYK test scale, which was specially prepared for the examination of print quality, was printed with Coldset Offset Printing on smooth papers coated with woodfree coated paper and woodfree uncoated paper, which are the best examples of uncoated papers and are widely used especially in book production. After printing, the surface of the papers was measured with a spectrophotometer and the dot growth and trapping values were determined. Surface and interfacial images of the prints were taken with a stereoscopic microscope and visual examinations were undertaken.

Keywords Coldset offset, Coated paper, Uncoated paper, Printability.

**Öz**

Kağıt ve mürekkep basılı malzeme üretiminde temel iki hammaddedir. Basılı mamül üzerinde görsel kalite çok önemlidir. Kağıt üzerinde, mürekkeple bir görüntüyü aslına uygun ve yüksek çözünürlükte basabilmek; kağıt ve mürekkep arayüzey ilişkisinin kalitesine bağlıdır. Mekanik odun hamurunun yoğun olarak kullanıldığı gazete kağıdı, kitap kağıdı ve saf selüloz esaslı 1.hamur kağıtlar gözenekli porozit yapıdadırlar. Bu kağıtlar üzerine baskı Coldset Ofset baskı ile gerçekleştirilir. Coldset ofset baskı, mürekkebin sıvı kısmının buharlaşması ve kağıda emilmesi yoluyla kurumanın geç gerçekleştiği bir baskı işlemidir. Mürekkebin tamamen kuruması (katılaşması) bazen birkaç gün sürebilir. Bu kuruma sürecinde kağıt bünyesindeki selüloz kapilerlerine dikey yönde nüfuz eden mürekkep, yatay yönde de aynı davranışı gösterir. Baskı basıncı nedeniyle mekanik olarak büyüyen (Dot Gain) nokta çapı kuruma sürecindeki kendiliğinden mikro adımlarla ilerleyerek daha da büyür. Dikey yönde ise kağıdın arka yüzeyine geçme eğilimindedir. Bu nedenle kağıt-mürekkep arayüzey davranışı mümkün olduğunca kontrol altında tutulması gereken önemli bir parametredir. Kağıdın pürüzlü yüzeyi, gözenekli yapısı ve nemi, mürekkebin viskozitesi ve kağıt yüzeyine basılan miktarı, NIP noktasındaki baskı basıncı, baskı odasının fiziksel şartları bu ara yüzey ilişkisinde etkilidir.

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Çalışmada yüzeyi kaplanmış ve kaplanmamış kağıtların üzerine baskıda görüntü kalitesine etki eden faktörler test baskısı yapılarak incelenmiştir. Baskı kalitesinin incelenmesi için özel hazırlanan CMYK test skalası, yüzeyi kaplanmamış kağıtlara en iyi örnek olan ve özellikle kitap üretiminde yoğun olarak kullanılan woodfree coated paper ve woodfree uncoated paper ile yüzeyi kaplanmış pürüzsüz kağıtlara, Coldset Ofset Baskı ile baskılar yapılmıştır. Baskı sonrası kağıtların yüzeyi spektrofotometre ile ölçülerek; nokta büyümeleri ve trapping değerleri tespit edilmiştir. Stereoskopik mikroskopla da baskıların yüzey ve arayüzey görüntüleri alınarak görsel incelemeler yapılmıştır.

Anahtar Kelimeler: Ofset baskı, Kaplanmış kağıt, Kaplanmamış kağıt, Basılabilirlik.

## Introduction

Ancient Egyptians invented papyrus paper in 3000 BC. Again in 2450 BC, animal skins were converted into parchment. The first organized paper production began in China in 150 BC. These papers were produced from softened hemp fibers, old fishing nets, plant bark, and water. In 105 AD, the first documentary record of the papermaking process was written in China, created by Ts'ai Lun. In Europe, the first paper production commenced in 1150. The paper then crossed the Atlantic Ocean in 1690 and the first paper was manufactured in Canada in 1803. Printing began in 1455 when Johannes Gutenberg (1400 - 1468) printed the 42-line Bible in his printing press in Mainz, Germany. In general, the second half of the XVth century is considered to be the period of the emergence and development of the printing press, and the XVIth century is considered to be the period of its popularization. By the beginning of the 16th century, printing had already expanded to all countries of Europe. The gradual spread of printing also boosted the consumption of paper, and new paper mills began to be established all over Europe, especially in the 16th century. The production of paper started with old rags, then linen and hemp were utilized, and cotton rags replaced them starting from the 16th century.

The improvement of printing technologies has required the improvement of paper, ink, and other materials. Various types of fibrous materials, gluing agents, fillers, and other special materials have been used to improve the printability and physical strength properties of the paper. To enhance the printability of the surface, calendering and coating processes were implemented.

The surface properties of the paper utilized in the production of printed products and the technological structures of pre-press preparation, printing, and post-press systems, and the know-how and skills to use them are the most important factors (Hayta, Sesli & Oktav, 2023). The principal aim of quality printing in all printing systems is to transfer a designed image onto the substrate in the closest way to the original. Even if all other quality parameters are optimum, the image will not be of high quality if the paper surface does not have the appropriate properties or if the appropriate screen frequency is not set.

Offset printing is the most commonly employed commercial printing process in the manufacture of newspapers, magazines, and cardboard packaging (Srividya & Thirunavukkarasu, 2016; Srividya, 2016). In the traditional offset printing system, the fountain solution is applied to separate the areas with and without images on the plate, i.e. to keep the ink from adhering to the non-image rough areas of the printing plate (Dhirender, Rajeev& Bijender, 2017).

The fountain solution is a multi-component mixture and is composed of approximately 95% water. However, usually, untreated water (tap water) needs to be prepared beforehand to convert it into a plate fountain solution. Furthermore, the fountain solution usually contains plate protectants, wetting agents, isopropyl alcohol (IPA), buffers, and anti-microbial additives (Kipphan, 2001).

Coldset offset printing is a process in which the liquid part of the ink gradually dries by itself through evaporation and absorption into the uncoated paper. The following parameters affect the ink absorption in the proceeding stages of the absorption (Akgul, Ozakhun&Tutak, 2006; Oktav et al., 2021);

- Viscosity of ink,
- Stickness of ink (tack),
- Physical and chemical properties of raw materials in the ink formulation,
- Porosity and homogeneity of paper,
- Physical conditions applied prior to and after printing,
- The behavior of the raw materials in the paper structure during the absorption,
- The printing pressure and the time at which the paper stayed under pressure.

In the case of coated and uncoated paper, the main difference is in the way the paper is produced. On uncoated paper, it can sometimes take a day or two for the ink to dry completely. Therefore, the friction resistance of the ink on the paper is very weak as it does not dry immediately after printing. Producing a printed product with coldset offset printing is more economical compared to other energy drying methods due to the lack of ink drying energy.

The micro-smoothness of the uncoated paper surface is known to be a factor affecting the print quality in offset printing (Rousu, Gane & Eklund, 2003). The ink absorption rate of uncoated paper is associated with the paper-ink contact angle (Rioux, 2003).

In the case of printing on uncoated paper, the permeation of ink into the paper significantly influences the print quality. An uncontrolled ink movement on/in the paper layer potentially leads to printing problems such as chromatic aberration, the print being seen from the other side of the paper, or ink migrating to the other side of the paper and smearing the ink on the paper surface onto the contact materials. Also, optical properties, mechanical properties, liquid permeability, etc. directly influence the quality of the printed image and printing applications (Yang, 2003).

Color as a variable that determines quality plays an important role in printing technology. The physical and physiological effects of colors are always significant in the perception and evaluation of colors (Akgül et al., 2022). The paper has a crucial impact on the qualitative characteristics of the printed product, as the properties of the paper surface directly influence the ink transfer and thus the basic optical properties of the print (Cigula, Tomašegović & Hudika, 2019). Paper topography properties are a quality-determining parameter in the full transfer of the image to the paper surface and print quality (Jurič et al., 2013). The factors affecting the print quality and printability of the paper are smoothness, surface strength, tensile strength, tear resistance, cleanliness, brightness, opacity, gloss, moisture content, dimensional stability, abrasiveness, and pH. The surface topography of the paper has a significant impact on the optical and physical characteristics of the paper as well as the print quality (Li & He, 2011).

Coldset offset printing is a printing process where drying occurs late by evaporation of the liquid part of the ink and absorption into the paper. The ink can sometimes take several days to dry completely (solidify). During this drying process, the ink penetrates the cellulose capillaries in the paper in the vertical direction and shows the same behavior in the horizontal direction (Yang & Liu, 2011). The dot diameter, which mechanically grows due to the printing pressure (dot gain), grows further in the drying process, progressing in spontaneous micro-steps. In the vertical direction, it tends to migrate to the back surface of the paper (Shinde, 2018). Therefore, the paper-ink interfacial behavior is an important parameter that should be maintained under control as much as possible. To achieve high printing efficiency and improve print quality, it is necessary to optimize the interaction of the printing ink and the paper surface very carefully (Bluvol & Carlsson, 2006).

Absorbent papers are an example of porous media. In all kinds of printing methods, the mechanisms by which porous materials such as paper absorb and stiffen the ink on it determine the printing speed and affect the final quality of the print (Hamada, Bousfield & Luu;2009). From the moment of printing with fluid ink on porous paper, the ink moves horizontally and vertically at the micro level during the physical drying process. This is the most important reason for the dot gain of porous high-grade paper pulp. Porous materials such as paper necessitate special fluid flow properties. Therefore, it is necessary to understand ink flow in the porous structure of the paper to achieve the desired print quality by controlling ink spreading and penetration (Aslannejad and Hassanizadeh;2017). Porosity and pore topology play an important role in the interaction of paper with liquids, along with surface tension, viscosity, and surface chemistry (Stankovská et al., 2014). The formula predicting fluid flow patterns in porous media can be expressed mathematically by Darcy's law (Desie et al., 2004). Porous media consisting of cellulose and absorbent fibers can be modeled using Darcy's law (Masood and Pillai;2010).

Darcy’s Law (1):

$$Q = \frac{-kA\,\Delta P}{\mu L} \qquad (1)$$

Q: Total discharge

k: Coefficient of permeability

A: Cross-sectional area of flow

ΔP: Pressure drop ($P_f - P_i$)

μ: Fluid viscosity

L: Length of medium

1 Darcy = $0{,}987 \times 10^{-12}$ $m^2$

The permeability K (2) for a porous medium with a length L and cross-sectional area A can be written as follows (Oktav; 1994);

$$K = \frac{Q\mu}{A\,(\Delta P/L)} \qquad (2)$$

Where Q is the total discharge rate, μ is the viscosity of the fluid (poise) and ΔP is the pressure difference along the sample length. The most commonly used unit for permeability is Darcy (d). One Darcy causes a fluid with a viscosity of 1 centipoise (1/100 poise) to flow at a flow rate of 1 $cm^3$ per second in a cube with sides of 1 cm.

**Materials and Methods**

Materials

In the study, woodfree uncoated paper and woodfree coated paper were used as substrates for test prints. Technical specifications of the papers are indicated in Table 1. Huber Coldset CMYK ink was used in the printing process. For the printing process, the image of the plates for the printing process was created on Kodak Trendsetter Q800 CtP Platesetter and the plate specifications are shown in Table 2. The printing process was undertaken on a 5-unit Comori S 40 offset printing machine. The printing machine and printing room conditions are presented in Table 3.

**Table 1.** Technical properties of the paper used in the study

| **Paper technical values** | **Woodfree uncoated (170 g/m$^2$)** | **Woodfree coated (80 g/m$^2$)** |
|---|---|---|
| Thickness (ISO 534) (µm) | 128.0 | 100.0 |
| Bulk (ISO 534) (cm³/g) | 0.74 | 1.25 |
| Brightness D65 (ISO 2470-2) (%) | 98.0 | 105 |
| CIE Whiteness (ISO 11475:2017) | 125 | 150 |
| Opacity ISO (2471) (%) | 97.5 | 92.5 |
| Gloss Hunter (ISO 8254-1) (%) | 72 | - |
| Gloss Lehmann (ISO 8254-2) (%) | 72 | - |
| Smoothness PPS 10 (ISO 8791-4) (µm) | 0.7 | - |
| Roughness Bendtsen (ISO 8791-2) (ml/min) | - | 250.0 |

**Table 2.** Plate specifications

| **Technical properties** | **Values** |
|---|---|
| Plate thickness | 0.3 mm |
| Screen frequency | 70 LPC |
| Screen angles | Cyan: 15<br>Magenta: 75<br>Yellow: 90<br>Black: 45 |

**Table 3.** Press machine and print room conditions

| **Technical properties** | **Values** |
|---|---|
| Fountain solution concentrate | %3 2-butoxyethanol, ethylene glycol, reaction mass of 5 -2H-isothiazol-3-one and 2-methyl-2H-isothiazol-3-one(3.1) 2,4,7,9-tetramethyldec-5-yne-4,7-diol |
| Fountain solution alcohol | % 4 IPA |
| Print room physical conditions | 22$^0$ C ve %55 Relative humidity |

Methods

For quality printing results, the physical conditions of the printing room, and the mechanical settings of the printing machine should be optimized and printing should be done by ensuring the optimum dot gain, ink densities, and color contrast. In this context, the following processes were followed in the study.

Offset printing plate preparation and printing

Positive thermal plates were prepared with Kodak Ctp Platesetter for offset printing. The prepared CMYK plates were scanned with PSS Plate Scanning System compatible with the printing machine. The ink settings of the plates attached to the printing machine were made automatically with PSS data. Paper thicknesses were measured with a micrometer as 0.1 mm for 80g/m$^2$ high-grade paper pulp and 0.14 mm for 170g/m$^2$ Coated Paper and automatic force settings were adjusted and test prints were realized at a speed of 6500 sheets/hour.

Printability properties of test papers

The surface measurements of the printed papers, both coated and uncoated, on which test prints were made, were performed by the CIE L*a*b* method using an X-Rite eXact spectrophotometer according to ISO 12647-2:2013 standard (International Organization for Standardization, 2013). The measurement conditions of the spectrophotometer were a D50 light source in the range of 400-700 nm and a polarizing filter with 0°/45° geometry. The difference between the colors of the test prints was calculated according to the CIE ΔE 2000 ISO 13655 standard (3);

$$\Delta E^*_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)} \quad (3)$$

The obtained data were analyzed and the effect of paper surface properties on the total color difference (ΔE) was investigated. Surface and interfacial images of the printing samples were taken with an electro stereoscopic microscope and ink penetration was analyzed.

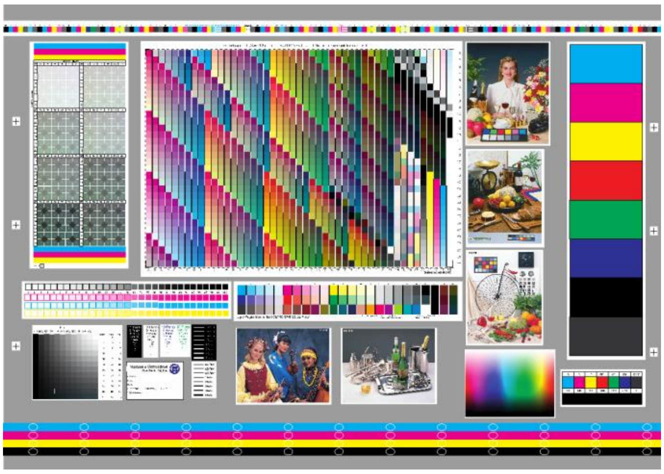


**Figure 1**. Test Print Scale

**Results**

Color measurement

In the printing process, the consistency of color is very crucial. Color measurement is done to detect the color difference between the standard color values and the color values of the printed sample. Especially in extra or Pantone printed colors, color reliability is more critical. For this reason, the desired color and the applied color must match. Color matching is quantitatively determined by measuring the color. Physical measurement of color is made by color measurement devices (Sesli & Hayta, 2023). Like optical density, apparent print color is a function of the light-reflecting properties of the combined paper-ink structure.

The quality of a printing paper is an essential factor in determining the quality of a color print (Kumaraguru et al., 2014). When the color measurement results and color gamut of the printed papers are examined, it can be seen that the topography of the paper affects the color results depending on the parameters of ink absorption and drying by the paper. In the color gamut (Figure 1), it is seen that woodfree coated paper is a color gamut that matches the ISO standard, while the color matching is confirmed by the delta e values below the standard. The color gamut of woodfree uncoated paper was within the limits of the ISO standard. This suggests that the color width is lower than expected.

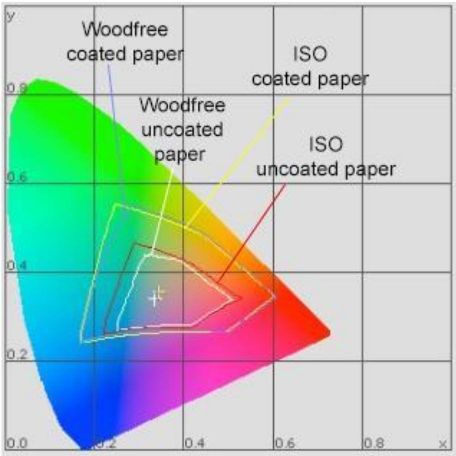



**Figure 2.** CMYK color gamut and ISO color gamut.

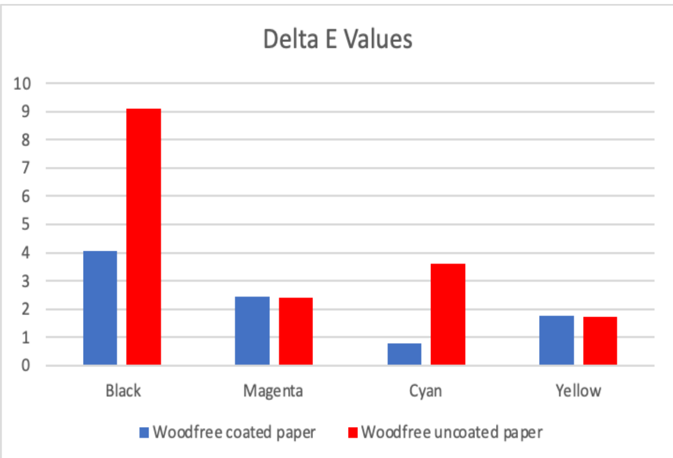
In the post-printing ΔE results, the color tolerance value for black, magenta, and cyan colors on uncoated paper was above the color tolerance limits of ISO 12647-2 standard. The ΔE result of the yellow color was found to be within the standard value limits on uncoated paper. The ΔE results of the coated paper for all colors were compliant with the standard.

**Table 4.** L*a*b* values after printing

| Standard values (ISO 12647-2) | | | | Woodfree coated paper | | | | Standard values (ISO 12647-2) | | | | Woodfree uncoated paper | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L* | a* | b* | | L* | a* | b* | | L* | a* | b* | | L* | a* | b* |
| Black | 16 | 0 | 0 | Black | 21,5 | 0,53 | 1,42 | Black | 31 | 1 | 1 | Black | 41,8 | 1,24 | 0,14 |
| Magenta | 46 | 72 | -5 | Magenta | 48,3 | 75,5 | -3,7 | Magenta | 54 | 58 | -2 | Magenta | 56,3 | 58,2 | -4,4 |
| Cyan | 54 | -36 | -49 | Cyan | 54,8 | -36 | -50 | Cyan | 58 | -25 | -43 | Cyan | 61,3 | -21 | -43 |
| Yellow | 88 | -6 | 90 | Yellow | 86,8 | -3,6 | 94,1 | Yellow | 86 | -4 | 75 | Yellow | 88,4 | -3,1 | 71,9 |

When ΔE results are checked, it is understood that the film layer formed by the ink depending on the paper surface properties and ink absorption are effective parameters in reflecting CMYK colors. It is also seen in the literature that the depth differences and pore structure on the paper surface are effective on the ink settling on the paper, print density, print gloss, and CIE L*a*b* colors (Aydemir et al., 2021; Mettänen, 2010). This situation confirms that the surface properties of the papers used in the study are effective on L*a*b* and ΔE values. While the denser ink film on the surface of the coated paper and the lower absorption resulted in colors closer to the standard values, the formation of a lower-density ink film on the surface topography of the uncoated paper and the higher absorption were effective in producing colors above the standard limits.

**Table 5.** ΔE values



Trapping

In wet trapping (or wet-on-wet ink printing) in multicolor printing, all of the overprinted ink can never be transferred onto the underlying ink. The capacity of printed ink to adhere to pre-printed ink is called trapping (Ragab & Kader, 2020). The trapping rate T is a value between 0% and 100%. The higher the trapping rate, the better the overprint (Panpan, 2014). As seen in Figure 3, it can be inferred that the trapping value is influenced by the surface roughness of the paper or cardboard (Jiang, 2010).

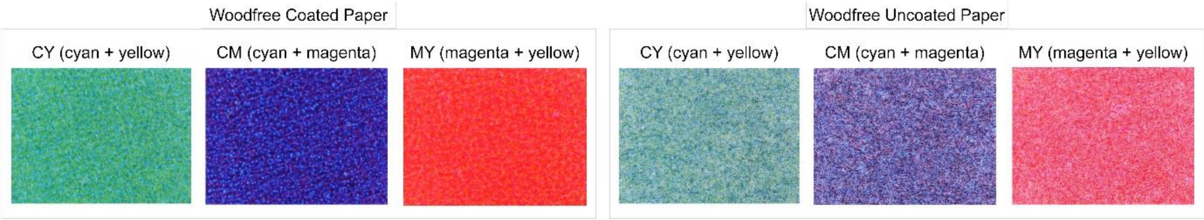
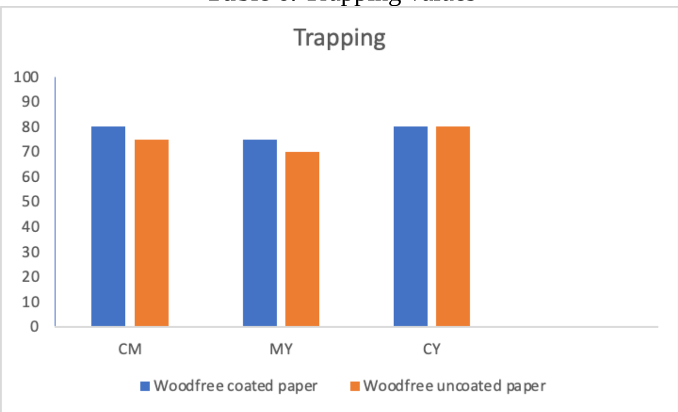



**Figure 3.** Trapping (wet on wet) microscopic images of test prints

In a print made at standard values, Cyan-Magenta-Yellow good trapping values should be as follows: Red 70%, Green 80%, and Purple 75.

**Table 6.** Trapping values




Dot gain

Changes in dot diameter are a critical factor for quality image transmission. These changes cause image degradation as they lead to tonal value increase and color shifts. Dot gain is caused by ink spreading around halftone dots under pressure at the NIP point. Various factors can contribute to the increase in the halftone dot area. These are printing plate properties, printing pressure, printing rubber properties, ink viscosity, and smoothness of the paper surface in physical drying (Elwan, 2017). In the test prints, these factors affecting the dot gain were taken under control and printed under optimum conditions and the dot gain values of both paper types remained within acceptable limits (Figure 4-5).

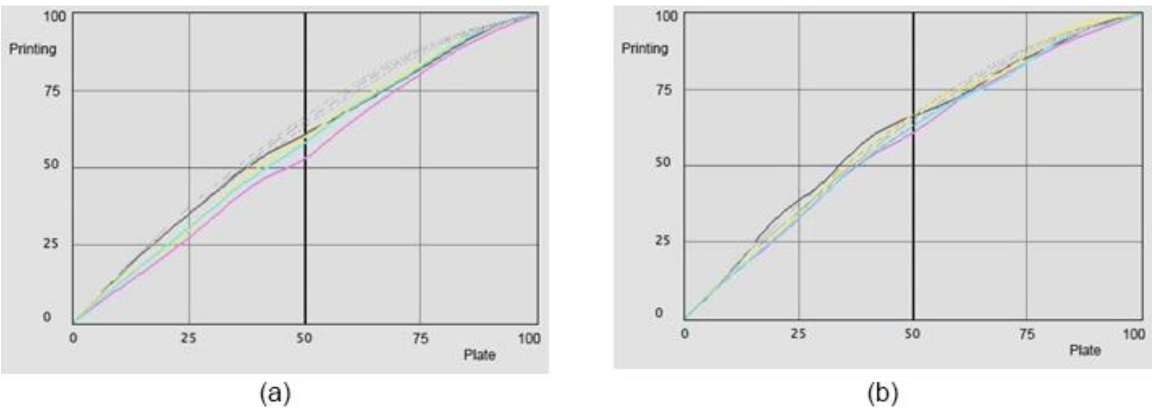



**Figure 4.** (a) Woodfree coated paper dot gain. (b) Woodfree uncoated paper dot gain

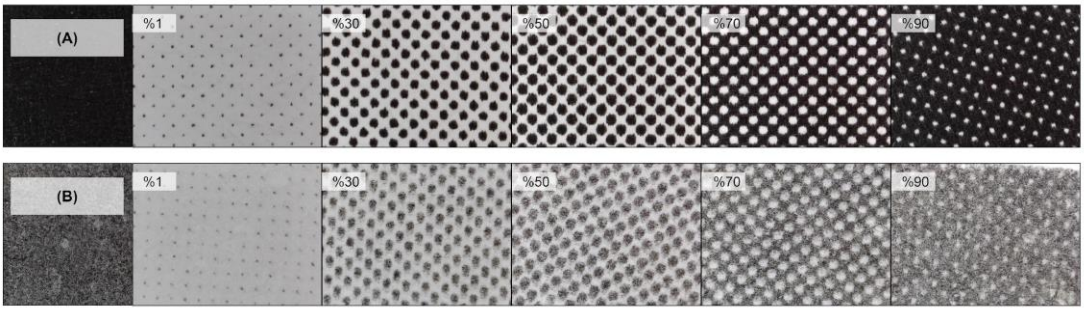



**Figure 6.** (A) Dots on woodfree coated paper. (B) Dots on woodfree uncoated paper.

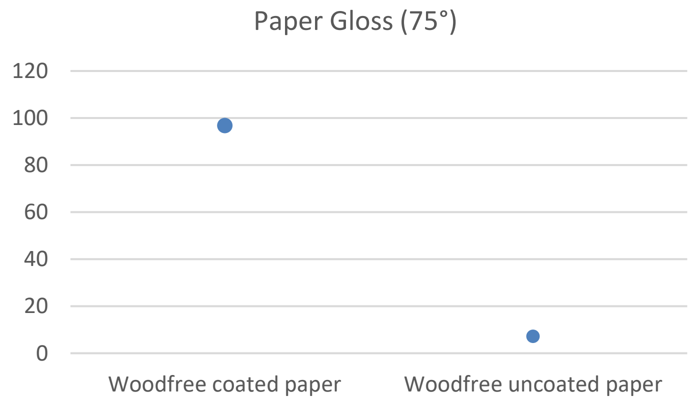
Gloss

In sheet-fed offset printing, print gloss is a function of the retention of the ink carrier by the paper, the glossiness of the paper, and the surface smoothness (Ülgen et al., 2012). Many researchers admit that print gloss is mainly influenced by a number of parameters related to paper coating, printing conditions, and printing ink. Print gloss is one of the key characteristics of a printed surface as it strongly influences print density, giving the print depth, a sense of quality, high sharpness, and higher image resolution (Elsayad et al, 2001).

Ink gloss is the specific reflection value of light incident on it. According to the TAPPI standard, gloss is defined as the reflection of light at λ (wavelength) 550 nm at an angle of 75° (Büyükpehlivan et al., 2022). Coated papers are coated with a mixture of water, pigment, and binder, dried, and calendered to make the surface glossy (Ülgen et al., 2019).

Gloss is associated with the surface smoothness of the material to be printed. The surface topography of coated and uncoated paper influences the gloss value. It is generally believed that gloss is increased when the ink film on a coated paper fills the coating pores on the paper surface (Ström & Englund, 2003). The gloss of printed materials also has a significant effect on perceived color. Colors with a matte surface appear less intensely colored and have lower chroma than colors with a glossy surface. This affects the chromatic parameters of the surface (Mikula, Čeppan, & Vaško, 2003). In the study, firstly, the gloss of the papers was measured at 75° (Table 7).

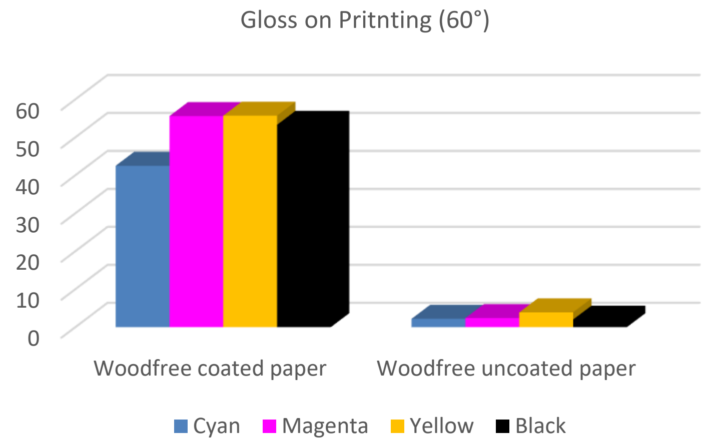
**Tablo 7.** Paper gloss values




When the post-print gloss measurements of coated and uncoated papers were evaluated, it was seen that woodfree-coated paper yielded higher print gloss while woodfree uncoated paper yielded lower gloss results (Table 8). Taking into account the surface topography of the papers, it is understood that the surface smoothness and reflection angle of the coated paper are very effective in the gloss value.

Printing gloss of coated paper according to international gloss values (MPI 2023) is "Semi-Gloss" in the range of 35-70 Units and printing gloss of uncoated paper is "Matte or Flat Finish" in the range of 0-5 Units.

**Tablo 8.** Print gloss values




## Conclusions

Inks are transported under pressure from the printing plate or printing rubber to the paper surface during printing. On the uncoated paper surface, they penetrate the paper under the influence of physical internal forces. Drying occurs when solvents or low-viscosity liquids are absorbed by the paper capillaries. The amount of ink on the paper plays an important role in determining the drying tendency. The rate at which uncoated paper absorbs ink is related to the paper-ink contact angle, the porosity, and the capillary structure of the paper. Self-physically drying inks can sometimes take several hours to dry completely. After the liquid part of the ink is absorbed into the paper and dried, a slight decrease in the densitometric value occurs. Also, it is not possible to obtain a very glossy ink film on the surface of absorbent papers with rough surfaces produced with mechanical pulp.

In printing on the surface of coated and calendered papers, the gloss increases significantly as the ink forms a stable film on the smooth paper surface.

The smoothness of the paper surface improves the contact between itself and the printing rubber at the NIP point, thus increasing the print gloss depending on the amount of transferred ink. Sizing the surface of the coated base paper before coating also improves the surface topography, thus increasing print gloss.

Mechanical dot gain is a measure of the difference between the dot diameter printed on paper and the dot diameter in the digital source file. On uncoated paper, mechanical dot gain occurs when the paper fibers, acting as capillary tubes, spread the liquid ink horizontally and vertically, increasing the dot size. Within limits, dot gain is not a printing defect. Dot gain is bound to happen and can be minimized with advanced software, calibration tools, and production processes. The graphic designer should take dot gain into account when designing halftone images. The elongation of the edges of the dots or dot slurring is not a dot gain but a printing defect. Excessive printing pressure at the NIP point, whether coated or uncoated paper, increases dot gain and causes chromatic aberration.

Color measurement is undertaken to detect the color difference between the standard color values and the color values of the printed sample. When the ΔE tolerance value between these two colors is less than 1, the eye cannot distinguish. However, it is not possible to obtain it with existing software, hardware, and printing systems. If ΔE is between 2-4, the difference between the reference color and the sample color is not very distinguishable, but it is acceptable. In cases exceeding these values, printing should not be done.

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