Balancing Regulatory Compliance and Color Performance: The CMYKOV Ink Gamut for Direct Food Contact Offset Printing

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Abstract

Direct food contact printing plays a critical role in food packaging, where inks must comply with strict safety regulations to prevent contamination. These regulatory and formulation constraints significantly limit pigment selection, which in turn affects the achievable color gamut. For brand owners and printers, this creates a challenge: how to maintain color fidelity and visual appeal while ensuring consumer safety and sustainability.

In a prior study, we quantified the color capabilities of an ink set compliant with direct food contact requirements by mapping achievable PANTONE® Solid Coated colors within a tolerance of $\Delta E_{00} < 2$. This analysis identified 1,801 colors that could be reproduced, providing a baseline for understanding the limitations imposed by pigment restrictions. Building on this foundation, and with sustainability in mind, we explored whether an extended color gamut (ECG) workflow could achieve acceptable color reproduction under compliance constraints.

This paper evaluates a CMYKOV (Cyan, Magenta, Yellow, Black, Orange, and Violet) ink set formulated for direct food contact (DFC) applications in sheetfed printing. The ink set evaluated in this study was developed in accordance with European DFC regulatory requirements and may not be compliant with regulations in other regions. The study examines the ability of CMYKOV to extend the chromatic range relative to the characterized reference printing condition CRPC6 of ISO/PAS 15339, while acknowledging its limitations compared to the broader Pantone colors commonly used in packaging printing. Although the addition of orange and violet inks expands the gamut beyond conventional CMYK, regulatory pigment restrictions introduce significant challenges, including reduced vibrancy, hue shifts relative to standard CMYK process printing, and a noticeable color cast in neutral gray areas. In addition, the absence of established density specifications complicates process control.

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The findings offer practical insights for color engineers, prepress specialists, and food packaging printers seeking to balance safety, sustainability, and color performance. By understanding the trade-offs involved in ECG workflows compliant with direct food contact requirements, stakeholders can make informed decisions about ink selection, color management strategies, and brand color expectations.

Introduction

Direct food contact (DFC) printing refers to printing applications where the printed surface physically contacts food, such as wraps, liners, and inner packaging. Unlike conventional packaging, these applications require strict adherence to food safety regulations, including EU Regulation EC 1935/2004 and U.S. FDA 21 CFR. These regulations significantly restrict allowable pigments and chemical components.

As a result, DFC ink systems exhibit reduced chroma and smaller color gamut compared to conventional packaging inks. At the same time, brand owners continue to demand strong visual appeal, color consistency, and sustainability. This creates a fundamental trade-off between compliance and color performance.

Expanded color gamut (ECG) printing has emerged as a potential solution by extending process color systems beyond CMYK to reduce reliance on spot colors. However, its effectiveness under DFC pigment constraints has not been fully explored. This study evaluates whether ECG, implemented through a CMYKOV (Cyan, Magenta, Yellow, Black, Orange, and Violet) ink set, can meaningfully expand achievable color in a compliant environment.

Background

A prior study conducted under European food safety regulations evaluated food-safe ink systems by mapping achievable PANTONE® Solid Coated colors using compliant pigments. It identified 1,801 reproducible Pantone colors within a tolerance of $\Delta E_{00} < 2$, thereby establishing a benchmark for achievable performance under regulatory constraints.

This baseline confirms that while limitations exist, a substantial portion of the color space remains reachable. The question remains whether ECG methods can extend this capability further without violating compliance requirements.

Methodology

Ink Set Specification

A six-color CMYKOV ink set was formulated using pigments compliant with DFC regulations. The selection of these six components was based on identifying the optimal combination of available food-safe pigments that could maximize achievable color gamut. The addition of Orange and Violet channels was intended to compensate for known weaknesses in conventional CMYK systems, particularly in the orange-red and violet-blue regions. However, due to regulatory limitations on pigment chemistry, these inks are less saturated than conventional packaging inks, making it necessary to evaluate their practical contribution to gamut expansion under real press conditions.

Press Trials and Test Form

Press trials were conducted using a purpose-built test form designed for comprehensive color characterization. The form included solid patches for each ink, tone scales for evaluating tone reproduction behavior, and a range of two-color overprints to assess ink interaction. A single substrate was used, featuring a coated front surface and an uncoated reverse side; both sides were printed. However, the analysis focused on the uncoated side, as it represents the actual surface that comes into contact with food in packaging applications. Measurements obtained from this test form served as the foundation for profile generation, overprint analysis, and overall system evaluation.

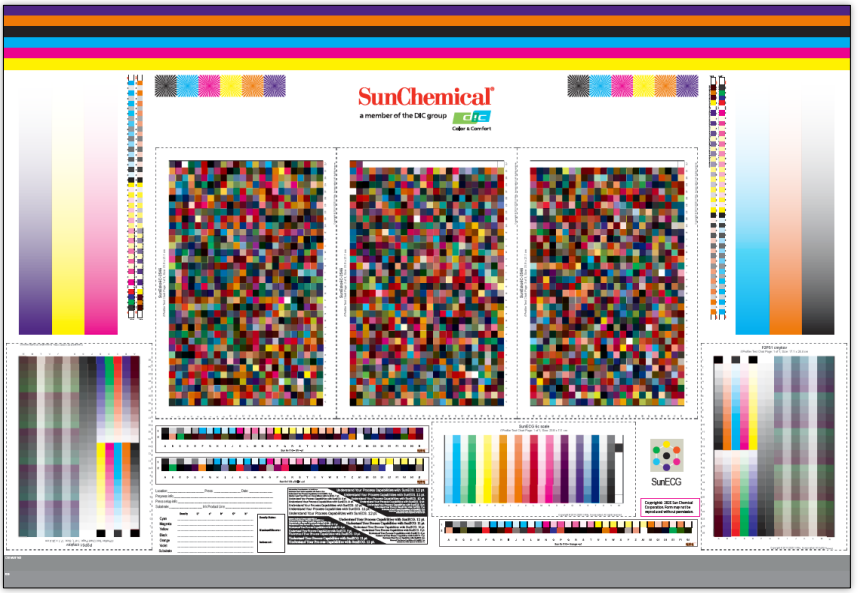


Figure 1. Six-color press test form used for CMYKOV characterization, including solid patches, tone scales, and key overprint combinations.

Characterization and Calibration

Printed sheets were measured using a spectrophotometer, and the resulting data were used to generate ICC profiles representing the CMYKOV system. Calibration was performed according to ISO 12647-2 Curve A, providing a standardized baseline for tone reproduction. However, because DFC ink systems do not have established density targets, solid ink densities were defined based on optimal color strength rather than fixed numerical values specified in ISO 12647.

Reference Comparison

To better understand the performance of the CMYKOV system, results were evaluated against CRPC6 (Characterized Reference Printing Condition 6), a widely recognized reference defined in ISO 15339-2. CRPC6 represents a stable and relatively wide commercial print gamut under controlled conditions and is commonly used as a benchmark for print characterization. Comparisons were conducted using measured values, overprint behavior, and overall gamut shape to assess the impact of regulatory constraints and the relative performance of the CMYKOV approach.

Results

CMYK vs. CRPC6 Performance

The comparison between DFC-compliant CMYK inks and the CRPC6 reference condition reveals clear differences in colorimetric behavior. Measurements of solid ink patches indicate that the DFC inks have reduced chroma across all primary colors, reflecting the limitations imposed by compliant pigments.

Magenta exhibits a noticeable hue shift toward the orange–yellow region, while Cyan deviates toward a green hue, contributing to improved green reproduction when overprinted with Yellow. Black achieves a significantly lower density than the CRPC6 reference, reducing contrast and shadow depth. These differences collectively contribute to a narrower and less saturated baseline gamut for the DFC CMYK system.

	DFC CMYK			CRPC6 CMYK			ΔC*	ΔH	ΔE_{00}
	L*	a*	b*	L*	a*	b*			
Cyan	53.2	-40.8	-37.9	56	-37	-50	-6.6	-10.9	5.6
Magenta	52.0	63.6	22.3	48	75	-4	-7.7	27.6	14.4
Yellow	91.3	-12.7	77.2	89	-4	93	-14.9	10.2	6.5
Black	25.8	0.8	3.8	16	0	0	3.9	0.0	7.7

Figure 2. Comparison of solid ink CIELAB values between DFC-compliant CMYK inks and CRPC6 reference condition.

Overprint Behavior

The interaction between inks in overprint areas plays a critical role in determining the overall shape and range of the color gamut. In the CMYKOV system, combinations involving magenta, orange, and yellow demonstrate high chroma, effectively expanding the gamut in the yellow–orange–red region. Conversely, the interaction between magenta and violet produces a low-chroma red–violet hue, indicating limited chromatic contribution in that region of the gamut. The cyan–yellow combination, while capable of generating relatively high-chroma greens, exhibits instability in tone progression, suggesting challenges in maintaining consistency across tonal ranges. These behaviors indicate that not all additional color channels contribute equally to gamut expansion, and their effectiveness depends on both pigment properties and interaction dynamics.

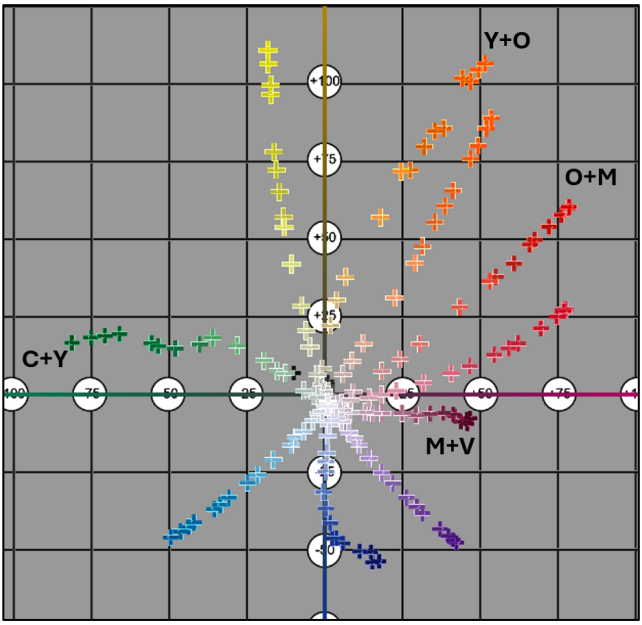


Figure 3. Two-color overprint behavior in the CMYKOV system, including M–O–Y, M–V, and C–Y combinations.

Gamut Expansion

Gamut visualization using two-dimensional projections highlights the extent of expansion achieved with the CMYKOV system. The addition of orange and violet channels produces noticeable expansion of the gamut boundary in the corresponding color space regions, particularly in the orange–red and violet regions where conventional CMYK systems are typically limited.

On the coated side of the substrate, the CMYKOV system exceeds the gamut of the CRPC6 reference, indicating strong chromatic performance under optimal conditions. However, on the uncoated side of the same substrate, representative of direct food contact applications, the overall gamut is reduced due to increased ink absorption and lower colorant efficiency. Despite this limitation, the CMYKOV system continues to demonstrate meaningful expansion relative to standard CMYK, particularly in specific color regions.

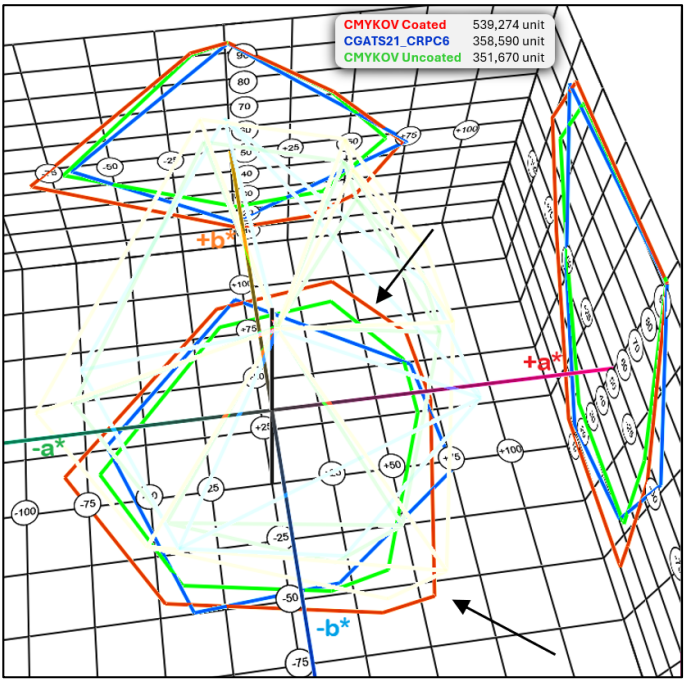


Figure 4. 2D gamut silhouettes of the CMYKOV system (coated and uncoated substrates) compared with CRPC6, illustrating relative gamut shapes and coverage across the color space.

Pantone Matching Capability

The ability to reproduce Pantone colors was evaluated to assess the practical value of the CMYKOV system in reducing reliance on spot inks. Using a process-only workflow, approximately 250 Pantone colors were reproduced within a ΔE_{00} threshold of less than 2, indicating high color accuracy. In addition, 1,641 colors fell within a ΔE_{00} range of 2 to 4, which may be acceptable depending on application requirements and visual tolerance. These results indicate that while only a limited number of Pantone colors can be reproduced with high accuracy ($\Delta E_{00} < 2$), a substantially larger portion can be approximated within a ΔE_{00} range of 2 to 4 using CMYKOV alone, offering potential efficiency and sustainability benefits in production environments.

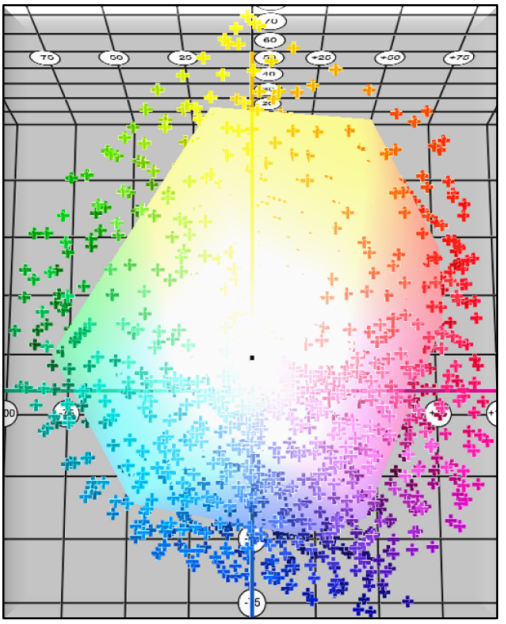


Figure 5. Pantone colors (cross marks) overlaid on the CMYKOV gamut on an uncoated substrate.

Discussion

Benefits of CMYKOV in DFC Printing

The results indicate that the CMYKOV system is capable of delivering targeted improvements in color gamut, even within the constraints of direct food contact regulations. The most significant gains are observed in yellow–orange–red color regions, where the addition of orange and the interaction between magenta and yellow contribute to increased chroma and improved saturation. These enhancements are well aligned with the performance requirements of a broad range of packaging applications, particularly in food packaging, where the reproduction of warm, high-chroma colors is critical for brand differentiation and visual impact. As a result, CMYKOV offers a practical means of improving color performance within direct food contact constraints.

System Limitations

The DFC ink system presents several limitations and challenges that must be acknowledged. The use of compliant pigments results in lower overall chroma compared to conventional ink systems, leading to reduced vibrancy in certain regions of the color space. Additionally, differences in hue angle between DFC-

compliant and standard CMY pigments introduce color shifts that can affect accuracy and consistency. Neutral tones also tend to exhibit a green cast, making it more difficult to achieve stable and visually acceptable gray balance. The lack of established density standards for DFC inks further introduces uncertainty in process control, leading to greater reliance on trial-and-error adjustments and visual evaluation during press setup.

Calibration and Process Control Challenges

Traditional density-based calibration methods are insufficient for managing the behavior of the DFC-based CMYKOV ink system. While density-based calibration improves overall appearance by reducing color casts and enhancing tonal balance, it does not fully resolve issues related to chroma limitations and hue shifts. Spectral measurement and advanced calibration approaches, such as G7+, should therefore be considered, as they are critical for maintaining consistency and achieving acceptable results. Achieving a balance between vibrancy, neutrality, and print stability requires careful control of ink film thickness, tone reproduction curves, and overall process conditions.

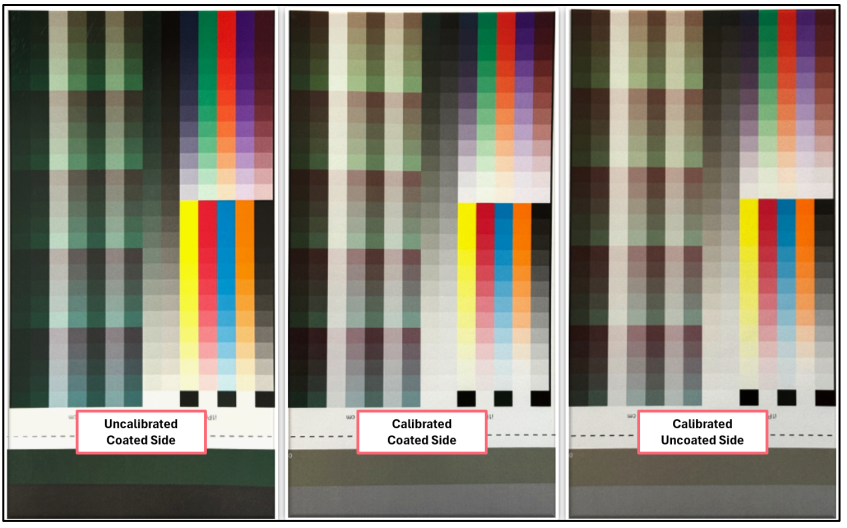


Figure 6. Visual comparison of uncalibrated and calibrated outputs on coated and uncoated substrates.

Image Reproduction Performance

Evaluation of image reproduction further highlights both the strengths and limitations of the CMYKOV system. Compared to standard CMYK, CMYKOV improves saturation and restores vibrancy in the orange and violet regions where

CMYK typically falls short. However, the CMYKOV image in this example appears darker, with noticeable hue shifts resulting from differences in pigment behavior and increased effective ink strength. When processed with customized adjustment curves, the image shows improved lightness, detail, and overall color accuracy, demonstrating the importance of tailored calibration.



Figure 7. Comparison of image reproduction using standard CMYK, CMYKOV (unadjusted), and CMYKOV with customized adjustment curves.

Practical Implications

The suitability of the CMYKOV system depends strongly on the type of printing job and the expectations of stakeholders. The system performs particularly well in packaging designs that emphasize warm colors, such as oranges, yellows, and reds, where its expanded gamut provides a clear advantage over standard CMYK. It is also well suited for high-saturation graphics, such as illustrations and imagery that do not rely heavily on neutral tones.

However, the system is less effective in applications that require accurate reproduction of blue-violet colors or deep reds, as the magenta–violet overprint does not provide strong chroma. Designs that rely heavily on neutral gray balance can also show a noticeable green cast, making it more difficult to achieve stable neutrals. In addition, applications that require very high vibrancy, similar to CRPC6 or non-compliant ink systems, may not achieve the expected results.

Successful implementation of CMYKOV requires careful management of expectations throughout the workflow. Accurate ICC profiling is critical in defining the achievable color space, while soft proofing provides a practical tool for communicating limitations to clients and stakeholders. On press, consistent process control—including stable ink film thickness, controlled press conditions, and spectral calibration—is essential to achieving repeatable results. Overall, CMYKOV should be positioned as a targeted enhancement strategy that offers measurable benefits for specific applications, rather than as a universal replacement for conventional ECG systems.

Conclusion

This study demonstrates that ECG printing using CMYKOV provides meaningful color improvements in direct food contact applications. While regulatory constraints limit overall color performance, targeted expansion is achievable, particularly in the yellow–orange–red regions of the color space. Successful adoption requires careful management of expectations, along with recognition of system limitations and the use of enhanced calibration and process control methods. These findings suggest that CMYKOV is most effective as a targeted enhancement strategy for specific applications, rather than a universal replacement for conventional ECG systems.

Future Work

Future work should focus on enhancing color performance through several key areas of development, including:

- Development of higher-chroma DFC-compliant pigments to expand the achievable color gamut
- Establishment of standardized density targets for DFC inks to improve process control and consistency
- Refinement of calibration methodologies to enhance gray balance and reduce residual color shifts
- Implementation of advanced profiling and color separation algorithms to better manage ink interactions and improve color accuracy

These advancements are expected to strengthen the robustness and applicability of ECG printing in regulated direct food contact applications.

References

ISO 12647-2:2013 Graphic technology — Process control for the production of half-tone color separations, proof and production prints — Part 2: Offset lithographic processes.

ISO 15339-2:2017 Graphic technology — Printing from digital data across multiple technologies — Part 2: Characterized reference printing conditions (CRPCs).

European Commission Regulation (EC) No 1935/2004 Materials and articles intended to come into contact with food.

U.S. Food and Drug Administration (FDA) Code of Federal Regulations Title 21 (21 CFR) – Food Contact Substances.