Evaluating Product Variation in Color Gamut Volume Estimation across Measurement Devices for Improved Analysis

Bilge Nazli Altay, Bruce Leigh Myers

Abstract

Color gamut volume (CGV) is an important characterization method to quantify the range of colors that a printing press can reproduce, based on the combination of press, substrate, and ink and measured using color measurement devices. Dissimilar color measurement tools and procedures can introduce variability that may complicate the comparison of the resulting color gamuts. This study investigates how different sampling and instrument selection affect CGV estimation. Using a standard CMYK test chart (ISO TC1617), prints were made on two paper substrates of different basis weight and surface properties using an electrophotographic digital press. The X-Rite iSis 2 XL, (revision A) and an X-Rite i1iO table with i1 Pro 3 (i1iO 3) were used to measure the printed charts. Measurements were collected in two ways: (1) repeated measurements of a single sheet to evaluate instrument precision, and (2) single measurement of multiple sheets to assess product variation. The resulting color gamuts were computed in CIE L*a*b* space to create ICC profiles and CGV was estimated using Chromix ColorThink Pro, version 3.09 using Microsoft Windows 11 Pro. The i1iO 3 consistently reported a larger gamut volume than the iSis 2 XL (on the order of ~3–4% higher), a difference found to be statistically significant. Despite this offset between devices, both instruments demonstrated high repeatability: the differences between ten-sample averaged volumes and one-sample volumes were <1% on average for each device. Certain individual color patches exhibited measurement variation (>1 ΔE*ab) between repeated scans, particularly in darker tones, but these had minimal impact on the overall gamut volume. The heavier, coated 120 lb cover stock yielded a ~9% greater gamut volume than the lighter 70 lb text stock, highlighting that substrate characteristics do affect color gamut capacity. Overall, our findings underscore the importance of measurement standardization and multi-sample averaging for reliable CGV analysis. The results highlight the need for standardized measurement practices and the use of multi-sample averaging to ensure accurate and reliable CGV evaluation. The study

Rochester Institute of Technology, Packaging and Graphic Media Science Department, 78 Lomb Memorial Dr, Rochester, NY 14623

concludes with recommendations for improving reproducibility, including instrument certification, clear reporting of measurement conditions, and the need for the development and adoption of a Gamut Comparison Index (GCI), an ISO compliant metric intended for both research and industry application.

Introduction

Color gamut volume (CGV) represents three-dimensional range of colors that a device or process can reproduce in a given color space. It is a fundamental comparative metric in color science, commonly used to quantify color capacity in printing systems, displays, and materials research [1]. By approximating the number of distinct perceivable colors producible, CGV provides a single value summary of a device's color reproduction capability. For example, typical printing reference conditions have CGVs ranging roughly from 84,000 up to 526,000 Lab^3 in CIE L*a*b* units for standardized datasets, such as CGATS/CRA Characterized Reference Print Conditions (CRPCs) (Figure 1). The CGV differences of CRPCs as defined by CGATS21 can be seen in Table 1. The CGV metric is valuable in research and quality control, as it allows comparisons of color performance between different materials, printers, or processes [2]. Recent software tools have even been developed to facilitate gamut comparisons across printing technologies and materials, underscoring the continued relevance of CGV in the graphic arts [1].

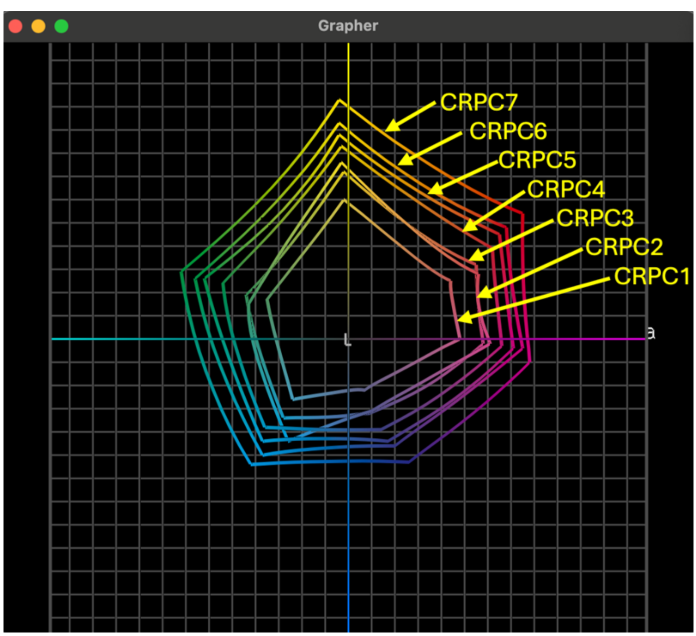

Figure 1. 2D color space comparison between standard CRPCs

CGATS 21	Color Gamut Volume (Lab^3)	Δ
CRPC1	84,269	
CRPC2	151,437	
CRPC2-CRPC1		67,168
CRPC2	151,437	
CRPC3	165,741	
CRPC3-CRPC2		14,304
CRPC3	165,741	
CRPC4	253,676	
CRPC4-CRPC3		87,935
CRPC4	253,676	
CRPC5	331,355	
CRPC5-CRPC4		77,679
CRPC5	331,355	
CRPC6	338,960	
CRPC6-CRPC5		57,605
CRPC6	338,960	
CRPC7	525,469	
CRPC7-CRPC6		136,509

Note: CGV calculated with ColorThink Pro 3.09 (Windows)

Table 1 Color gamut volumes of Characterized Reference Printing Conditions as defined by CGATS21

As interest grows in the impact of sustainable materials on printed color performance, accurate CGV estimation has become increasingly important for making meaningful comparisons. Substrate composition and coatings can significantly impact color gamut [3,4] and are commonly reported in testing of substrates and coatings.

Further, as environmental concerns push the industry toward more natural, bio-based ingredients in paper coatings [5], researchers have observed changes in color reproduction. For instance, replacing conventional synthetic latex binders with starch-based nanoparticles in paper coating has been shown to alter the gamut volume and color vibrancy of prints [4]. Such material substitutions may reduce or shift the range of achievable colors due to changes in ink receptivity, gloss, or optical properties of the print. This demonstrates that material-driven differences in gamut volume are real; however, quantifying these differences and attributing them to materials requires a high degree of measurement precision. In practice, the magnitude of CGV changes from material innovations can be on the order of only a few percent. For example, research reported that the gamut volume of a biopolymer coated paper differed by roughly 20,000 Lab^3 units from a standard coating [3]. When multiple measurement of the same sample was conducted, the variability overlapped with the differences caused by formulation changes: this condition made it challenging to confidently isolate the effect of the material itself from the instrument variation [3]. This scenario highlights a critical need for examining the sources of variation in CGV calculation.

Measurement methodology and instrument selection are potential sources of significant variability in reported gamut volumes. In the current practice, different research groups or laboratories may use different spectrophotometric devices, software algorithms, or sampling procedures when measuring printed color charts. The lack of a standardized method can lead to inconsistencies—one instrument might consistently report a larger or smaller gamut volume than another for the same print, due to differences in spectral response, aperture size, calibration, or chart reading technique. Prior studies in color reproduction tolerance have emphasized the importance of instrument precision and consistency: even within calibrated systems, small differences in measurement can translate into meaningful differences in color metrics [6]. The study suggests that to ensure accurate color reproduction and fair comparisons of results, it is therefore essential to evaluate how precise and repeatable our color measurement instruments are, and how much variability different devices introduce [6].

Another consideration is the measurement procedure itself. Automated chart readers are not designed for the exact patch positioning that is achievable with spot-reading instruments (Figure 2), contributing to variability in consecutive and subsequent readings. It is not uncommon for automated chart measuring instruments to average several readings in a single patch, and color variation within that patch can contribute to measurement variability. Furthermore, factors such as backing material, measurement aperture size and alignment, and even the software/operating system used for calculations may influence the outcome.

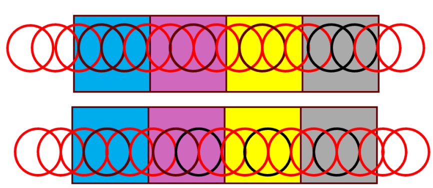

Figure 2. Spot reading positioning illustration of automated spectrophotometers

If CGV is to become a reliable metric for evaluating differences in materials, at minimum the processes, software, and instrumentation should be reported along the CVG, else CVG could lose credibility as a reliable metric.

One example of a metric that has lost credibility at the consumer level is paper brightness: despite standardized procedures as defined by ISO and TAPPI, paper companies frequently report brightness without reference to the procedure used to calculate the figure. This is especially true with office papers. As many commonly used color measurement instruments feature the ability to measure a brightness index without claim of traceability to a recognized industry standard, consumers have no reliable means to compare values simply reported as “brightness” without further disambiguation. Some paper labels even use the term “bright” rather than “brightness”, such practices inhibit the ability for consumers to compare the brightness of different paper stocks and confuse the marketplace. Without further examination, CVG risks similar ambiguity as a metric for researchers and practitioners, underscoring the need for the present research.

Similarly, color gamut volume suffers from a lack of standardized protocols and consistent reporting practices. Given these concerns, this study aims to systematically examine the variation in color gamut volume calculations arising from two key factors: (1) the choice of color measurement instrument, and (2) the sampling methodology (multiple substrate measurements vs. single substrate measurement). By doing so, we seek to quantify the magnitude of instrument-induced differences and random measurement noise in CGV estimates and inform ongoing discussions involving CGV. The goal is to apprise both researchers and industry practitioners of potentially critical variables that affect gamut volume analysis, thereby improving the reproducibility and reliability of color gamut comparisons in printing research and workflows.

Experimental Procedure

Printing and Color Profiling Process: The printing press used for the study was a Xerox iGen 5 digital press (dry toner electrophotographic technology) in a controlled laboratory setting (temperature 23±1 °C, relative humidity ~50%) to minimize environmental variability. The press’s color management was set to a GRACoL2013 CRPC6 CMYK reference profile. Two paper substrates were selected to represent different material characteristics: (1) 70 lb text weight and (2) 120 lb cover weight from the Veritiv Endurance Silk and Cover line, respectively. The color test target used was the TC1617x chart, which contains 1,617 color patches sampling the CMYK printer color space (Figure 3).

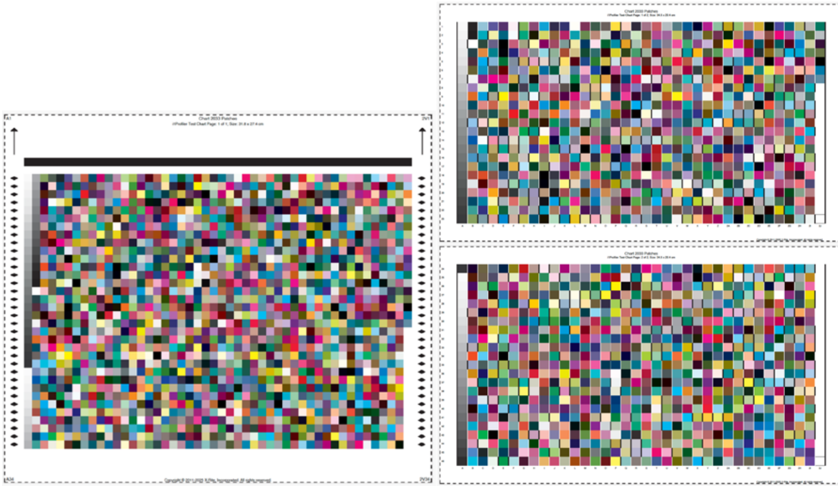

Figure 3. TC1617x color test chart prepared by i1Profiler
for the iSis 2 XL (left) and the i1 Pro 3 (right)

Two color measurement instruments used were the X-Rite iSis 2 XL and the X-Rite i1 Pro 3. The i1 Profiler software was used for data collection and building the profiles with the software settings of illuminant/observer condition D50/2°, measurement mode M1, backing white. After measurement, the spectral data were converted to CIE L*a*b* coordinates for each patch, Figure 4 shows the ICC profile preparation workflow. To compute the color gamut volume from the measured data, Chromix ColorThink Pro (version 3.0.9) on a Windows workstation was used. ColorThink Pro can calculate the convex hull of the point cloud of colors in Lab space and report the volume in cubic units of Lab, known as Lab^3.

Figure 4. ICC profile preparation workflow

To assess measurement variability, the experiment was designed to capture two main factors: instrument differences and sampling differences. For each combination of paper substrate and measurement instrument, two measurement approaches were employed: (1) Repeated measurement of a single print: One representative print (sheet) of the TC1617x chart was measured ten times in succession. Any variation in the L*a*b* readings for a given patch across these ten measurements reflects the instrument's measurement noise, positioning variability, and short-term stability. This step is referred to as the single-sheet 10× measurement condition. (2) Single measurements of multiple prints: Ten different printed sheets of the chart were measured, each once. These ten sheets were the replicate prints produced in the same print run. It is recognized variability of the printer could be a contributing factor to the overall variance here. This step was the 10-sheet 1× measurement condition (multiple samples).

Additionally, to analyze patch measurement differences, we performed a pairwise colorimetric comparison of repeated measurements on the same sheet. For the single-sheet 10x data, the color difference (ΔE_{ab}) was calculated for each patch between every pair of the ten measurements (45 pairs in total for each of the 1,617 patches). This analysis allowed us to determine how many patches showed noticeable differences between repeated readings and whether any systematic trends were present (e.g., specific colors or areas of the chart being less consistently measured). Patches with ΔE_{ab} greater than 1.0 were flagged, as this threshold is commonly used to signify small but potentially perceivable differences in color.

Substrate characterization: Consistent with previous research providing CGV as a metric to evaluate substrates and coatings, Roughness (μm^2) and air permeance (mL/min) were evaluated using a Parker Print-Surf (PPS) testing instrument (*TMI, Industrial Physics, New Castle, DE*). For both roughness (with soft backing) and porosity measurements, the PPS clamping pressure was set at 1000 kPa. Paper thickness (µm) was determined with a digital thickness gauge (*TMI*). The permeability coefficient of the coated samples was calculated using Equation 1, where K represents the permeability coefficient (μm^2), Q is the PPS flow rate (mL/min), and L is the paper thickness (m).

$$K=0.048838 \ x \ Q \ x \ L \qquad (1)$$

Statistical analyses: Statistical analyses were conducted using JMP Pro 18 out on the volume data to assess significance of differences. A two-way analysis of variance (ANOVA) with factors Instrument (iSis 2 XL vs i1iO 3) and Sampling method (single vs multi, and by substrate) was used to evaluate their effect on measured CGV. Post-hoc *t*-tests were used to compare the mean volumes between instruments for each substrate, with a significance criterion of $\alpha = 0.05$. These tests determine if the observed differences between devices are statistically significant relative to the variability in repeated measures.

Results and Discussions

Figure 5 presents a comparison of the physical properties of the paper substrates. Measurement of surface roughness revealed that 70 lb substrates exhibit significantly less roughness values (0.68 µm) compared to 120 lb substrates (1.12 µm), indicating substantial differences in surface topography. Thickness measurements demonstrated that 120 lb substrates (334 µm) are thicker than their 70 lb counterparts (94 µm). Furthermore, air permeance testing showed that 70 lb substrates possess less permeance values (5.53 mL/min) relative to 120 lb substrates (7.55 mL/min), a finding consistent with the calculated permeability coefficients (0.00012 µm² for 70 lb; 0.00003 µm² for 120 lb). The results demonstrate that the 120 lb cover is a heavier, thicker sheet with a rougher surface and higher air permeability, whereas the 70 lb text is a lighter, thinner sheet with lower air permeance (denser fiber structure). Such physical differences can potentially impact ink absorption and gloss, and thus the CGV.

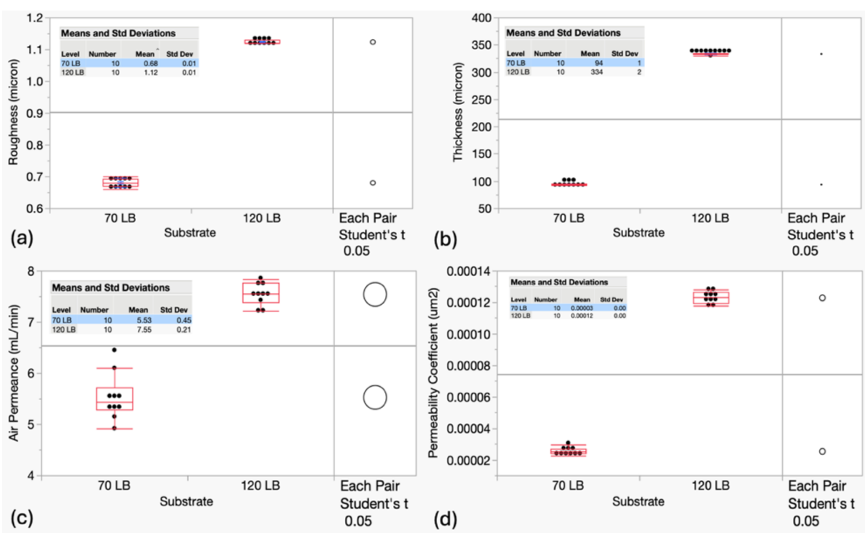

Figure 5. Comparison of the physical properties of the paper substrates:
(a) roughness, (b) thickness, (c) air permeance and (d) permeability coefficient

Figure 5 and Figure 6 present color gamut volumes for each substrate, comparing the two measurement devices, i.e., iSis 2 XL and i1iO 3, respectively, under two conditions of multiple-sample (10-paper) and single-sample (1 paper). The i1iO 3 consistently reported higher gamut volumes than the iSis 2 XL for the same prints, as illustrated in Figure 8. This trend held across both substrates and for both sampling conditions. As Table 2 shows, for the 70 lb paper, the i1iO 3 measured an average CGV of about 328,000 Lab^3, compared to about 318,000 Lab^3 with the iSis 2 XL (a difference of ~10,000 Lab^3). For the 120 lb paper, the i1iO 3 yielded

~357,000 Lab³ vs iSis 2 XL ~345,000 Lab³ (difference ~12,000 Lab³). In percentage terms, the i1iO 3's readings were approximately 3% higher on the lighter stock and approximately 3.5% higher on the heavier stock. Statistical analysis confirmed that these instrument-related differences are significant ($p < 0.01$ in the ANOVA for the main effect of instrument). In other words, the choice of spectrophotometer introduced a systematic bias in the estimated CGV.

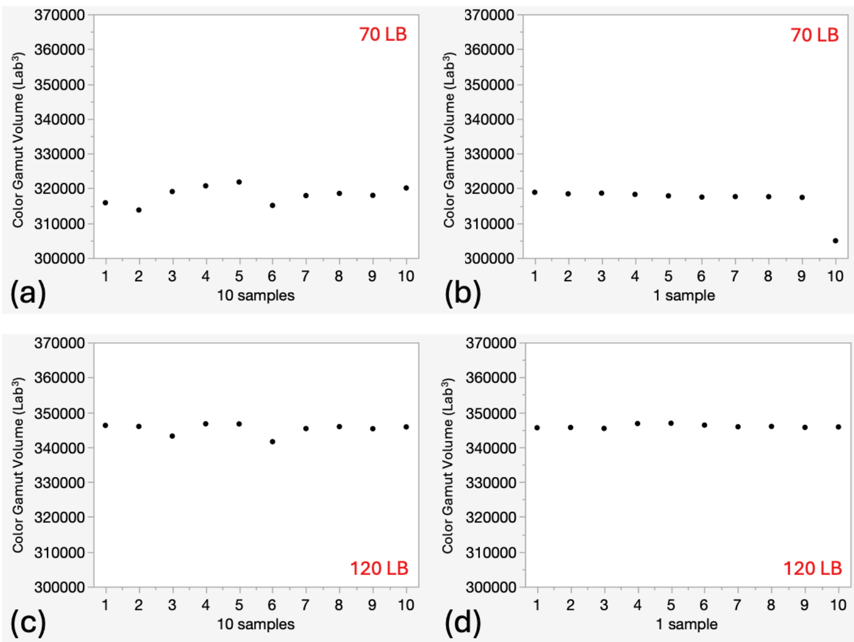

Figure 6. Color gamut volumes measured using iSis 2XL

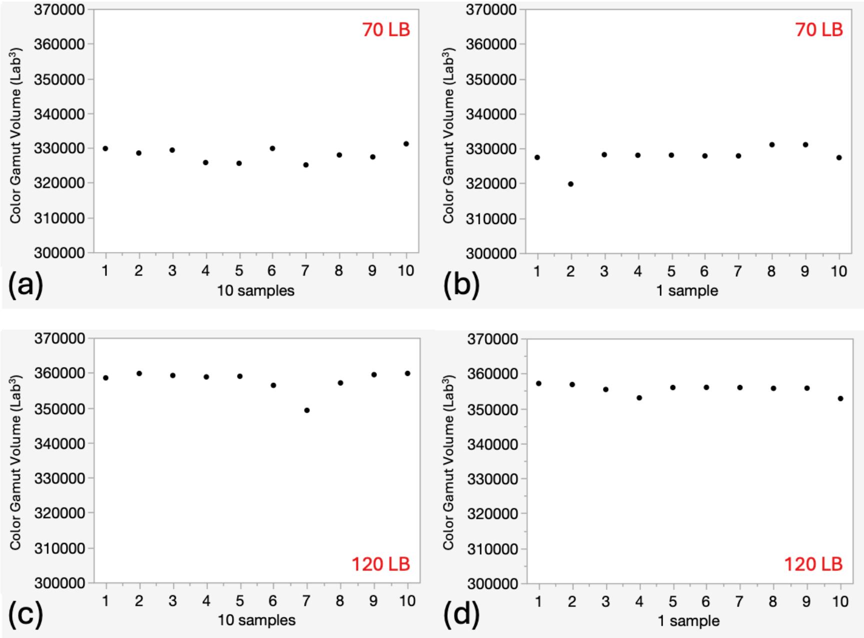

Figure 7. Color gamut volumes measured using iSis 2XL

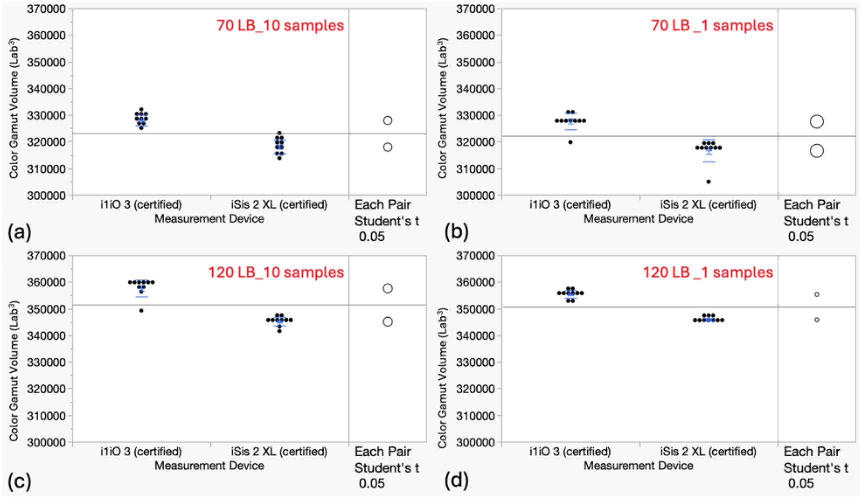

Figure 8. Differences between instruments and previous versions tested instruments with each paper type and measurement procedure

	70 LB		120 LB	
(a) Maximum	10 samples	1 sample	10 samples	1 sample
i1iO 3	331,176	331,058	359,796	**357,136***
iSis 2 XL	321,808	**318,847***	346,673	346,638
Δ	9,368	12,211	13,123	10,298
(b) Average				
i1iO 3	328,056	**327,663***	357,720	**355,468***
iSis 2 XL	318,077	**316,692***	345,237	345,958
Δ	9,979	10,971	12,483	9,510

Note. *"Δ" indicates the difference between CGVs. The * and bold text highlight Lab^3 volumes referred to in the text.*

Table 2. Maximum and average CGV (Lab^3) for each substrate, comparing the two measurement devices under two conditions: multiple-samples (10 sheets 1x measurement condition) and single-sample (single sheet 10x measurement condition).

Turning to the pairwise colorimetric comparisons, each patch of the single sheet readings for the 70# and 120# papers was compared to the others with the respective instruments, as illustrated in Table 3. Colorimetric standard values were calculated from an average of each of the 10 patch readings, and ΔE_{ab} was calculated. Those patches with a ΔE_{ab} greater than one was flagged for subsequent examination, with a goal of examining instrument reputability and informing the contribution of colorimetric differences to CGV differences.

Pairwise comparisons of single sheet 10x measurement condition

	1 & 2	2 & 3	3 & 4	4 & 5	5 & 6	6 & 7	7 & 8	8 & 9	9 & 10
	1 & 3	2 & 4	3 & 5	4 & 6	5 & 7	6 & 8	7 & 9	8 & 10	
	1 & 4	2 & 5	3 & 6	4 & 7	5 & 8	6 & 9	7 & 10		
	1 & 5	2 & 6	3 & 7	4 & 8	5 & 9	6 & 10			
	1 & 6	2 & 7	3 & 8	4 & 9	5 & 10				
	1 & 7	2 & 8	3 & 9	4 & 10					
	1 & 8	2 & 9	3 & 10						
	1 & 9	2 & 10							
	1 & 10								
Total pairs	9	8	7	6	5	4	3	2	1
# of combinations	45								
# of patches per sheet	1,617								
Total patch comparisons	72,765								

Table 3. Pairwise comparisons of single sheet 10x measurement condition

Evaluations of the 120# paper with the iSis 2 XL exhibited 44 pairwise comparisons with a ΔE_{ab} greater than 1.0, as shown in Table 4. Of these, 17 (>38%) were attributable to two patches, suggesting inner patch variance or an anomaly of a single reading on one of the targets. It is noted, however, that all of the patches with a ΔE_{ab} greater than one was relatively dark: none had an L* value greater than 50.

Patch	Count	Position	L*	a*	b*	C*	h_{ab}
Y41	9	Y41	19.00	13.29	8.18	15.61	31.60
Y22	8	Y22	31.00	-3.19	24.81	25.01	97.32
I2	4	I2	12.65	0.79	1.30	1.53	57.87
A48	3	A48	11.61	1.05	-0.26	1.14	274.62
B32	3	B32	52.11	58.28	50.80	77.32	41.08
Z10	3	Z10	20.18	18.47	10.55	21.27	29.74
O12	2	O1	24.31	1.22	8.58	8.67	81.93
Q25	2	Q25	14.35	9.31	-2.35	9.61	345.85
Y3	2	Y3	21.54	17.73	12.33	21.60	34.81
D20	1	D20	47.93	-57.07	22.40	61.31	158.57
D46	1	D46	22.93	22.26	15.69	27.23	35.19
E26	1	E26	13.69	0.40	2.74	2.77	81.61
M18	1	M18	27.05	-11.54	15.73	19.51	126.28
N24	1	N24	18.44	15.75	5.45	16.67	19.09
X2	1	X2	40.17	1.38	29.75	29.78	87.35
2C39	1	2C39	22.77	11.42	15.39	19.17	53.41
2F10	1	2F10	15.21	9.37	1.79	9.54	10.80
sum	44						

Table 4. Pairwise comparisons of single sheet 10x for 120# paper, iSis 2XLwith $\Delta E_{ab} > 1.0$

Similarly, an evaluation of the 70# paper with the iSis 2 XL exhibited 41 pairwise comparisons with a ΔE_{ab} greater than 1.0, as shown in Table 5. Of these, 26 (>63%) were attributable to two patches, suggesting inner patch variance or an anomaly of a single reading on one of the targets. Of the nine patches with a ΔE_{ab} greater than one, three had L* values greater than 50, but the patches accounting for 35 out of 41(>85%) of the instances with a ΔE_{ab} greater than one had L* values less than 50.

Pairwise comparisons of single sheet 10x for 70# paper, iSis 2XLwith ΔE_{ab} > 1.0

Patch	Count	Position	L*	a*	b*	C*	h_{ab}
1257	15	E26	16.56	0.68	2.22	2.32	72.95
1256	11	F10	24.21	0.02	-2.61	2.61	270.32
555	2	L24	39.16	30.26	32.38	44.32	46.94
218	2	L27	23.43	0.33	-22.32	22.32	270.85
571	4	L43	42.08	-6.79	-19.98	21.11	251.22
634	4	R7	58.99	-35.44	3.78	35.64	173.92
552	1	N10	63.32	-29.63	-21.11	36.38	215.47
250	1	2A8	51.84	2.19	-0.72	2.31	341.89
823	1	2A9	23.00	9.98	-28.41	30.11	289.35
Sum	41						

Table 5. Pairwise comparisons of single sheet 10x for 70# paper, iSis 2XLwith ΔE_{ab} > 1.0

For readings with the i1iO 3, with the 120# paper there were 30 pairwise comparisons with a ΔE_{ab} greater than one, as shown in Table 6. Seventeen of the instances here are attributable to two patches (>56%). Again, this suggests inner patch variation or a single reading anomaly. Unlike the iSis 2 XL, a mix of light and dark patches resulted in a ΔE_{ab} greater than one.

Pairwise comparisons of single sheet 10x for 120# paper, i1iO3 with ΔE_{ab} > 1.0

Patch	Count	Position	L*	a*	b*	C*	h_{ab}
993	9	U33	76.75	3.00	7.59	8.16	68.42
1611	8	2H27	41.02	-39.68	-0.44	39.69	180.63
1250	3	2A2	62.78	6.48	53.74	54.13	83.12
1039	2	V31	49.47	-0.28	37.68	37.68	90.43
1615	1	2H31	16.23	-3.90	-3.92	5.53	225.20
141	1	C45	40.87	10.25	-18.38	21.04	299.14
289	1	G1	50.87	-59.66	19.77	62.85	161.67
605	1	M29	72.08	-21.20	61.97	65.50	108.88
647	1	N23	33.69	-31.60	6.95	32.36	167.60
875	1	S11	49.41	42.24	13.59	44.37	17.83
947	1	T35	41.37	15.65	19.70	25.16	51.53
1555	1	2G19	73.88	7.19	4.52	8.50	32.16
Sum	30						

Table 6. Pairwise comparisons of single sheet 10x for 120# paper, i1iO3 with ΔE_{ab} > 1.0

Finally, using the 70# paper with the i1iO 3, unique results were noted. Here, 1,257 pairwise comparisons resulted in a ΔE greater than one, with 89 exhibiting a ΔE_{ab} greater than two. In examining the patches with the highest ΔE_{ab} values as shown in Table 7, commonalities in patch position were noticed. For example, instances with the highest ΔE_{ab} values those in positions S36, S38, S39 and S41, along with those in positions T35, T36, and T37. This indicates possible instrument positioning anomalies, or perhaps paper or printing variations in specific areas.

Pairwise comparisons of single sheet 10x for 70# paper, i1iO3 with ΔE_{ab} > 1.0, most frequently occurring

Patch	Count	Position	L*	a*	b*	C*	h_{ab}
900	21	S36*	87.11	-3.20	12.97	13.43	103.69
947	21	T35**	39.34	-13.38	-7.31	15.72	207.46
901	21	S37*	29.34	30.18	18.48	35.42	31.73
857	21	R41*	66.96	2.52	0.61	3.28	21.48
902	21	S38*	43.73	56.05	5.53	56.48	6.46
903	21	S39*	52.53	-20.93	-5.63	22.37	193.68
948	21	T36**	28.78	18.90	4.81	19.59	13.71
949	21	T37**	73.44	5.89	-3.11	6.90	332.03
859	20	R43	80.60	-3.04	10.02	10.5	106.17
951	20	T39*	64.34	-4.43	19.93	20.52	105.01
905	20	S41*	63.20	-6.19	29.13	30.02	102.51
993	19	U33	44.53	-49.70	19.05	53.35	158.18
809	19	Q41	46.62	28.91	35.60	46.47	51.64
627	19	N3	51.70	36.42	24.79	44.48	36.40
811	19	Q43	37.62	49.01	-5.73	49.56	349.86
765	19	P45	54.57	9.58	46.56	47.70	78.22
992	19	U32	40.77	29.54	31.07	43.15	49.93
810	19	Q42	67.90	-19.64	-5.81	20.60	196.61
1039	19	V31	49.91	-4.13	-1.59	4.92	204.06

Note. *The * and ** highlight respective adjacent patch positions with multiple occurrences of ΔE* > 1.0.*

Table 7. Pairwise comparisons of single sheet 10x for 70# paper, i1iO3 with ΔE_{ab} > 1.0, most frequently occurring

Despite the colorimetric differences as noted in the pairwise comparisons, there seemed to be little to correlate them to the recorded CGV differences. Reasonable expectations of the automated color measurement instruments tested, given their intended purpose and design, suggests that they performed well in terms of providing the colorimetric information required to construct ICC profiles and color gamuts.

A follow-up evaluation of legacy instruments in the same application exhibited some curious and potentially noteworthy results, as shown in Figure 9. These evaluations, using the legacy i1iO 2 and iSis XL (revision E) showed a marked difference from the new i1iO 3 and iSis 2 XL, specifically, the gamut volumes calculated from the data obtained legacy instruments markedly decreased in subsequent readings. While it is recognized that the legacy instruments used were not current in their factory calibrations, it is likely that some of the differences may be inherent in the metrology of the instruments themselves. This suggests that the current instruments perform more repeatably than their forbears, emphasizing the need to report instrument details along with CGV. Furthermore, Figure 10 illustrates the CGV estimation of an identical color profile evaluated on Windows (left) and Mac (right) systems, highlighting the importance of reporting the computer platform used for accurate interpretation. Figure 11 represents the GCI comparison, new method for comparing gamuts through subtraction, addition, and shared volume analysis, offering clearer visual and numerical insights.

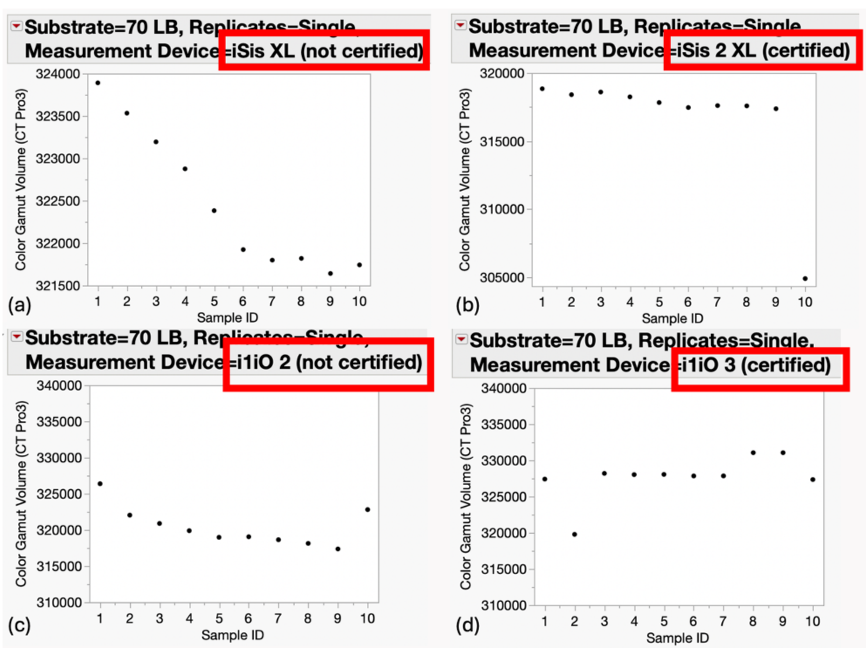

Figure 9. Differences between instruments and previous versions tested instruments with each paper type and measurement procedure

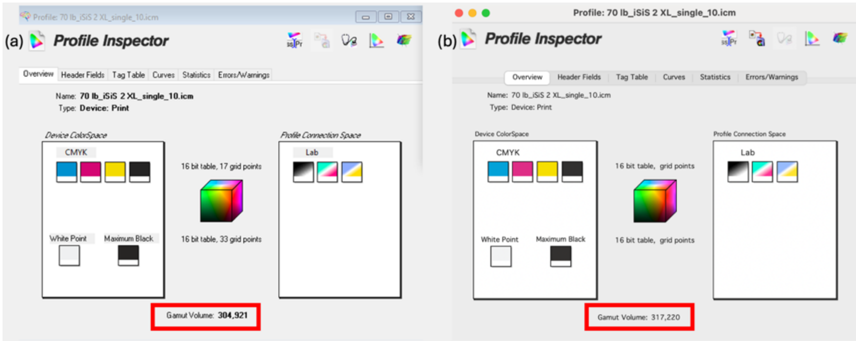

Figure 10. CGV estimation of a same color profile estimated on Windows (left) versus Mac (right) platforms

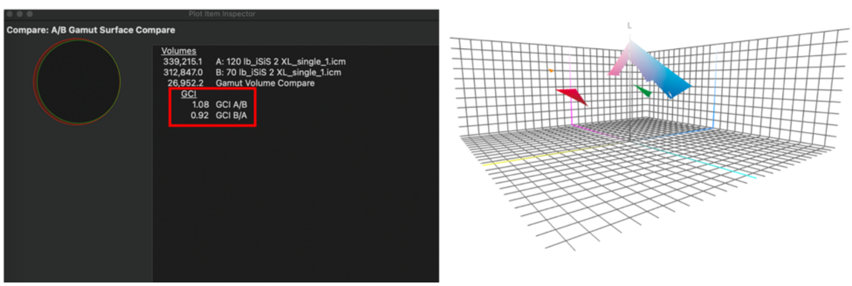

Figure 11. The Gamut Comparison Index (GCI) between the two color profiles shows that Profile A is 8% larger than Profile B. The image on the right highlights the areas where Profile A extends beyond Profile B.

Conclusions

As could be reasonably anticipated, the dissimilar papers evaluated performed differently in terms of CGV. Within each paper, however, statistically significant differences in CGV were realized in both single sheet and multiple sheet comparisons, underscoring the need for more standardized, averaging procedures when researchers report CGV as an evaluation metric.

Despite statistically significant differences, the clinical importance of gamut volume difference is another matter. To better understand CGV, it is helpful to turn to ISO/PAS 15339-Characterized Reference Printing Conditions (CRPC) for context, as illustrated in Table 1. Here, it is noted that the CGV difference between CRPC2 and CRPC 3 is 14,304 Lab^3; CRPC2 represents Typical Heatset Newsprint and CRPC 3 represents Typical Premium Uncoated; these differences are within the range of CGVs reported by the current study. The next closest adjacent CRPCs are between CRPC5 (representing Typical Publication Coated, Typical Publication Printing) and CRPC6 (representing Typical Premium Coated, Large gamut (typical Commercial Printing), with a CGV of difference 57,605 Lab[3]. While reporting such differences helps to frame the differences observed in the present study, further evaluation seemingly points to future possible psychophysical studies in this domain. However, such studies would require careful selection and production of standardized images.

The present study also identified myriad factors that were noted as influencing CGV calculations, including those that are software-related and those that are related to the hardware utilized. In terms of software, analyses subsequent to those reported suggested differences in the versions of CGV calculation solution, and even differences with the same software version on different computer operating systems. While X-Rite i1 Profiler was the only profile building software utilized here, it is likely that a different profile building software could yield different results. This suggests that CGV values should be accompanied by details of the software, version, and operating system used.

The hardware utilized also impacted CGV: these instruments are designed for ease of use when reading numerous color patches and are not typically considered laboratory-grade instruments. Pinpoint readings in a particular area is not practicable with such instruments, in inner-patch variance and sampling can influence measurement disparity. When used for their intended purpose to build ICC-profiles, they perform very well, and while accuracy and precision are important their application intention understandably suggests that ease of use is prioritized over the ability to utilize their readings in an absolute way.

Further, the present study used new instruments with current firmware. As they were new, they were the latest models, and their factory certifications were valid. Since the introductions of previous versions of these measurement devices, these instruments have undergone improvements and modifications in firmware and likely metrology such as optics. A subsequent analysis of older instrumentation resulted in even more variation in CGV calculations than those that are reported here, underscoring the need for such details to accompany reports of CGV.

In conclusion, the observations suggest that the inherent variations involved in producing CGV values render reporting those numbers alone to be of limited value for subsequent comparisons. Researchers are advised to include supporting, ancillary information along with reported CGV values, including measurement methodology, such as averaging and other measurement procedures, along with details on the hardware and software utilized, including versions and the operating system. Without such details, consumers may justifiably discount the reported CGV values as critical to the materials investigated.

References

1 López-Baldomero, et al. (2022). New software for comparing the color gamuts generated by printing technologies. Optik, 261, 169194.

2 Chovancova-Lovell, V., & Fleming III, P. D. (2009). Color gamut – a new tool for the pressroom? TAPPI Journal, 8(2), 4–11.

3 Altay, B. N. (2023). Investigating the effects of using biopolymer in paper coatings on printability and oil absorption (Doctoral dissertation, Marmara University, Istanbul, Turkey).

4 Altay, B. N., Carver-Kubik, R., Williams, J., et al. (2024). Starch-based nanoparticles as a replacement for synthetic latex: A comprehensive assessment of printability and colorimetric characteristics. Color Research & Application. Advance online publication. https://doi.org/10.1002/col.22941

5 Li, H., Qi, Y., Zhao, Y., Chi, J., Cheng, S. (2019). Starch and its derivatives for paper coatings: a review. Progress in Organic Coatings, 135, 213–227. https://doi.org/10.1016/j.porgcoat.2019.05.015

6 Beretta, G., Sansone, A., & Rizzi, A. (2012). Assessing color reproduction tolerances in commercial print workflow. In Color Imaging XVII: Displaying, Processing, Hardcopy, and Applications (Proc. SPIE Vol. 8292, 82920U). https://doi.org/10.1117/12.911899

Acknowledgement

The authors thank Mary Ellen Gauntlett, Director of The HUB Print & Postal Operations, and Alixaundra Fergus of Digital Production for their support in providing facility access, assisting with the digital printing process, and donating substrates. They also thank Ayyuce Guzide Teke for her vital contributions to data collection during the development of the ICC profile. We also thank Chromix and X-Rite for their generous and ongoing support of our academic programs and research initiatives.