TAGA NextGen

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

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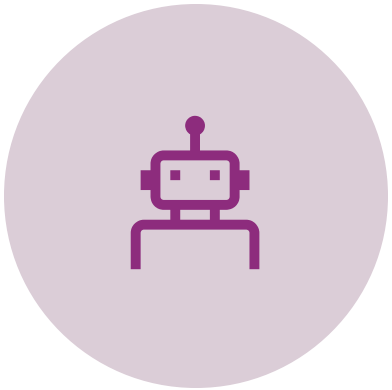
RIT

Outline

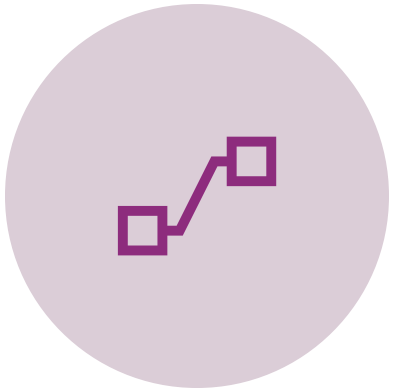
BACKGROUND
& MOTIVATION

RESEARCH
OBJECTIVES
& GOALS

PROBLEM
STATEMENT



MATERIALS
& METHODS



CONCLUSIONS,
IMPLICATIONS, &
FUTURE STUDIES

Q&A

Background & Motivation

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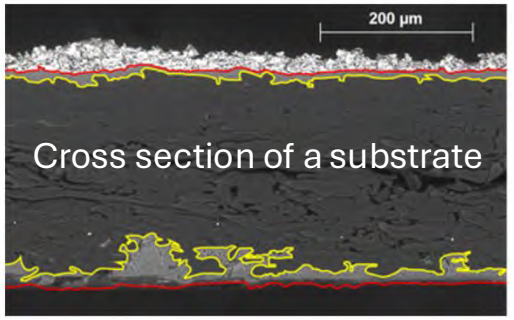
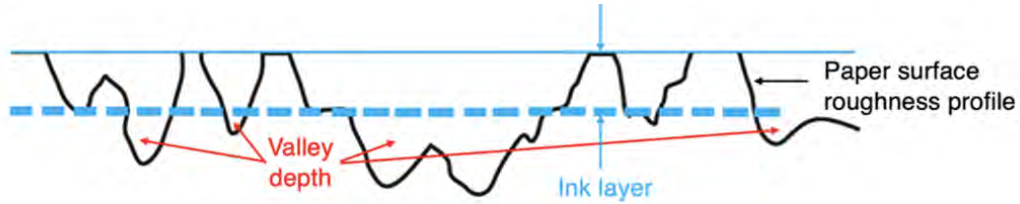


- Importance of Color Gamut Volume (CGV) Estimation
  - A key relative metric in color science and printing, display technologies and materials to quantify color capacity [1].
  - Intended to approximate the number of distinct perceptible colors.
- Shift towards natural materials
  - Environmental concerns drive interest in eco-friendly substrate ingredients [2,3].
- Impact on color gamut
  - Replacing synthetic ingredients with natural ones can affect the CGV, altering the range and vibrancy of colors [4].

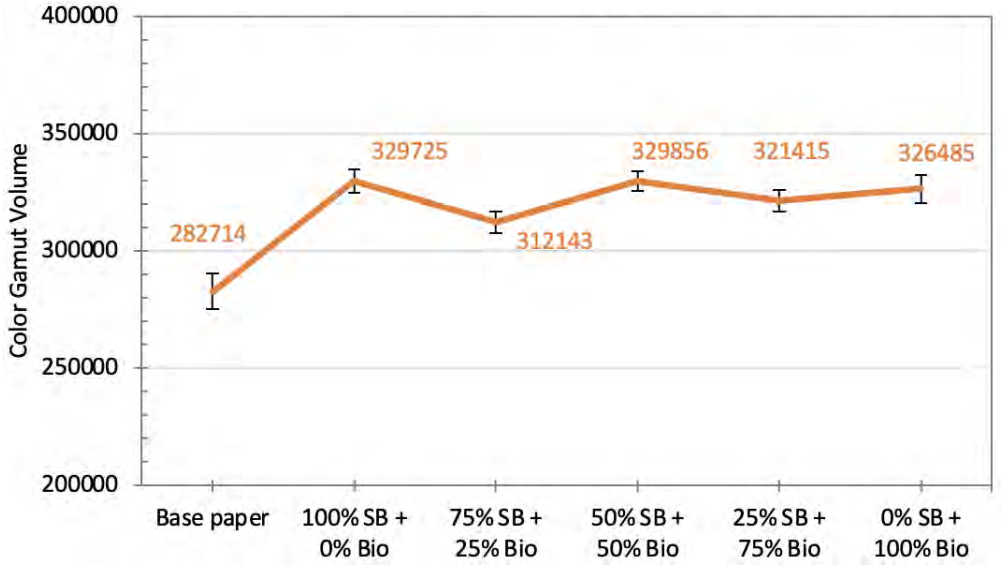


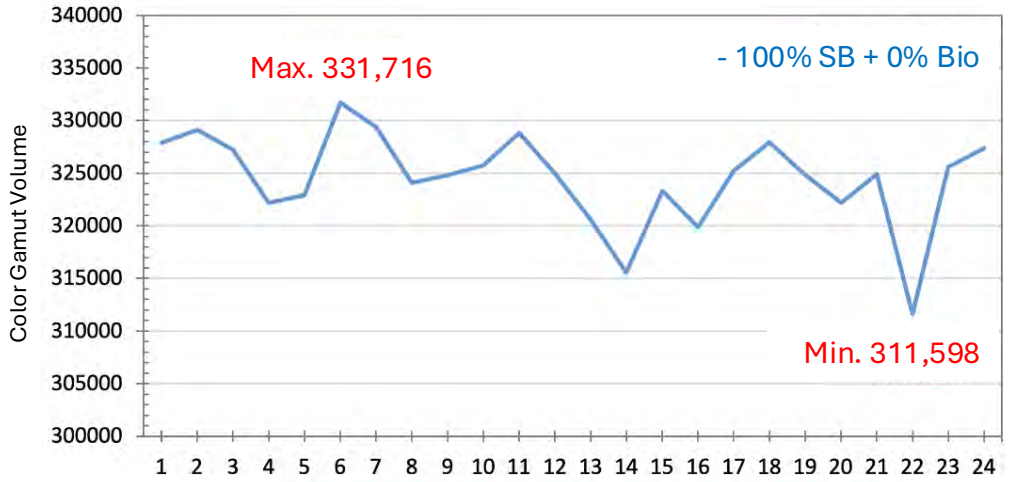
[1] López-Baldomero et al. (2022). New software for comparing the color gamuts generated by printing technologies, Optik, 261, 169194.
[2] Li H, Qi Y, Zhao Y, Chi J, Cheng S. Starch and its derivatives for paper coatings: a review. Prog Org Coat. 2019;135:213-227. doi:10.1016/j.porgcoat.2019.05.015
[3] Chovancova-Lovell, V., Fleming III, P. D. (2009). Color gamut – a new tool for the pressroom? Tappi Journal, February 2009, p. 4-11.
[4] Altay, Carver-Kubik, Williams et al. (2024). Starch-based nanoparticles as a replacement for synthetic latex: A comprehensive assessment of printability and colorimetric characteristics, doi: 10.1002/col.22941

CGV Comparison

- Typical CGV 84,000 – 526,000 (CRPC range)
- Measurement fluctuations (~20,000) overlap with the differences between formulation, making it hard to isolate material effects—highlighting the need for a variation study [4].
  - The overlap complicates attributing variations to material changes.
- Accurate color reproduction requires evaluating the precision and consistency of color measurement instruments [5].

Replacing styrene-butadiene (SB)
with a starch-based nanoparticle biomaterial (Bio)





Same substrate measured multiple times
(Tappi standards – 10 sampling)

[4] Altay, B. N. (2023) Investigating the effects of using biopolymer in paper coatings on printability and oil absorption, Ph.D. Dissertation, Marmara University, Istanbul, Turkiye.
[5] Beretta et al. (2012). Assessing color reproduction tolerances in commercial print workflow, Proc. SPIE 8292, Color Imaging XVII: Displaying, Processing, Hardcopy, and Applications, 82920U (24 January 2012); https://doi.org/10.1117/12.911899

CGV Could Become “New Paper Brightness”

- Consumer Paper Brightness Commonly Reported by Vendors
  - Standardized
    - T525 and T452 (TAPPI 457nm)
    - ISO 2470 and ISO 2469
  - Brightness “Indices”


Perfect for everyday printing and copying.
Le choix idéal pour l'impression et la photo
au quotidien.
Perfecto para la impresión y copias cotidian
20 lb
75
92
500
8½"
216 x
HeavyWeight Project Paper
Papier pour Projet Poids Lourd
40
150
95
8.5 11
216 279
250
Multipurpose Pa
Bright and versatile – perfect for inkjet and
96 BRIGHT
20 LB.
500 SHEETS
100% SATISFACTION
MultiPurpose20
20
75
96
161
emium Multipurpose Prin
Versatile Paper Good for Most Jobs
24 Pound
Extra White 97 Bright
8.5 x
Premium Bright W
Inkjet & Laser Paper
Heavier weight. Superior printing.
98 BRIGHT
28 LB.
500 SHEETS
LETTER
8.5" x 11"
216 mm x 279 mm

Research Objectives & Goals

Examine the variation in CGV calculations

- As reporting gamut volumes is common in many research applications, the objective is to **examine the variance** in the process **with a goal of informing future researchers** and consumers of potentially critical issues and variables.

Problem Statement

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The lack of standardization in measurement methodologies results in variations that hinder reproducibility and precision.

Challenges involved with automated color measurement, small color patches, and substrate inconsistencies.

A structured evaluation of measurement consistency and material performance is necessary.

Materials & Methods

CVG & Pairwise Colorimetric Comparisons

Materials and Methods

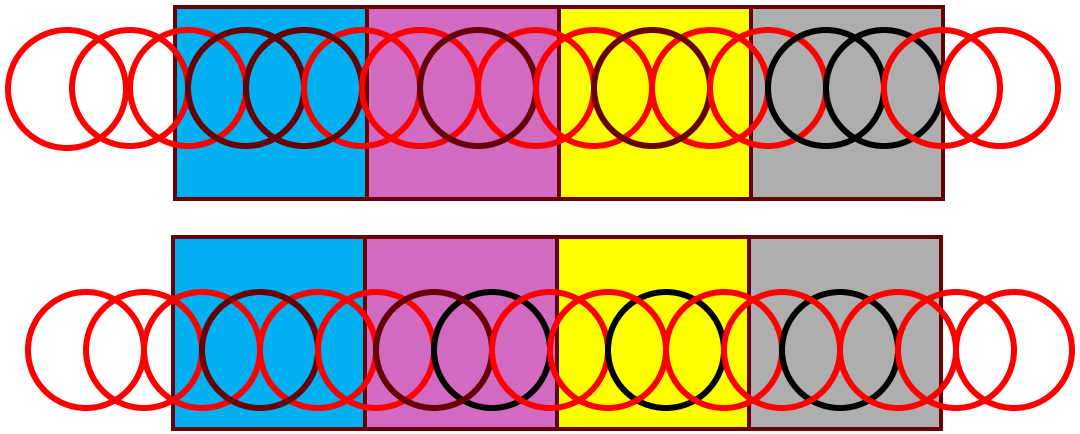
- Printing press
  - Xerox iGen 5 electrophotography tech.
- Substrates
  - Veritiv Endurance Silk Text and Cover (70 LB, 120 LB)
- Measurement tools
  - X-Rite iSis 2 XL
  - X-Rite i1iO with i1 Pro 3
- Software
  - i1 Profiler, Chromix ColorThink Pro 3.0.9 (Windows)

Variables

- Surface Qualities of Substrate
- Software
  - Profiling Software
  - Gamut Volume Calculation Software Version
  - Operating System
- Color Measurement Instrument
- Imaging on Substrate
  - “Within Patch” Variation
- Normal Colorimetric Variables, e.g., Measurement Condition ISO13655:2009

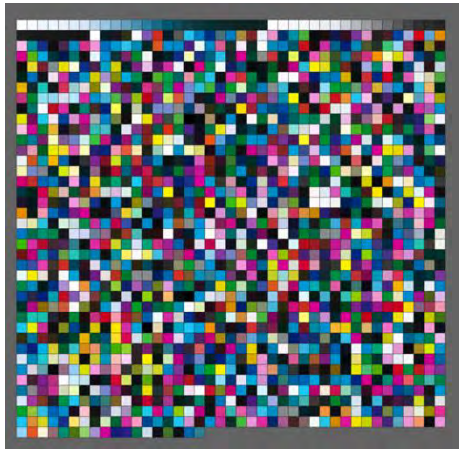
Variables: Automated Patch Measurement

- x, y positioning of measurement aperture
- Multiple readings in single patch averaged
- Within patch variation



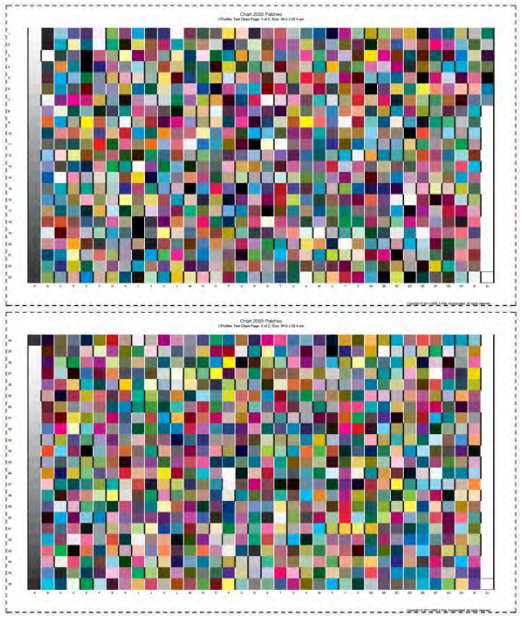
Experimental setup

- Test chart design
  - TC1617x
- Printer configuration
  - CMYK source: GRACoL2013 CRPC6
- Measurement procedure
  - 1 sample x 10 measurement
  - 10 sample x 1 measurement

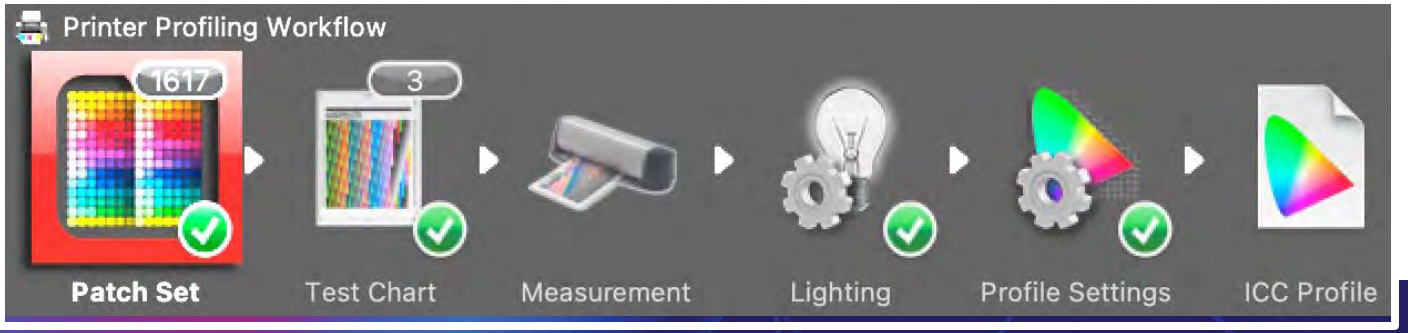


TC1617x

iSis XL

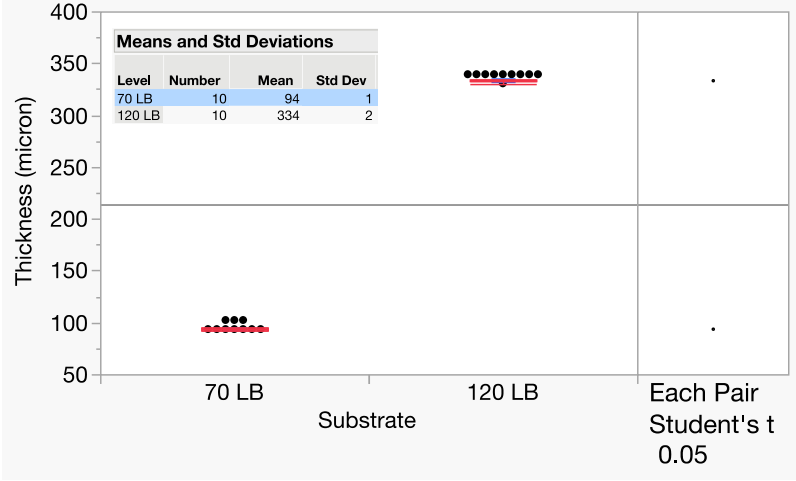


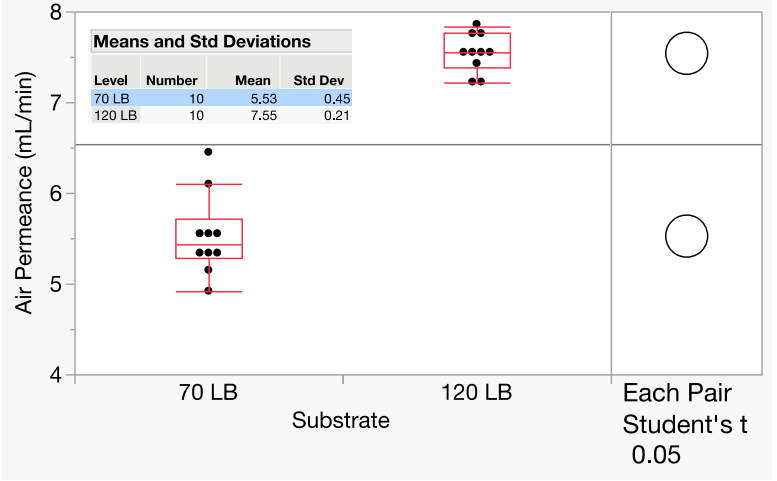
i1iO 3

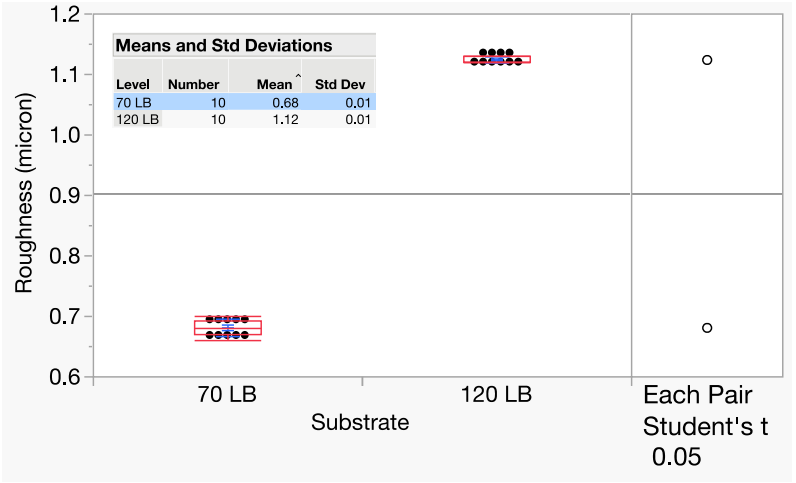


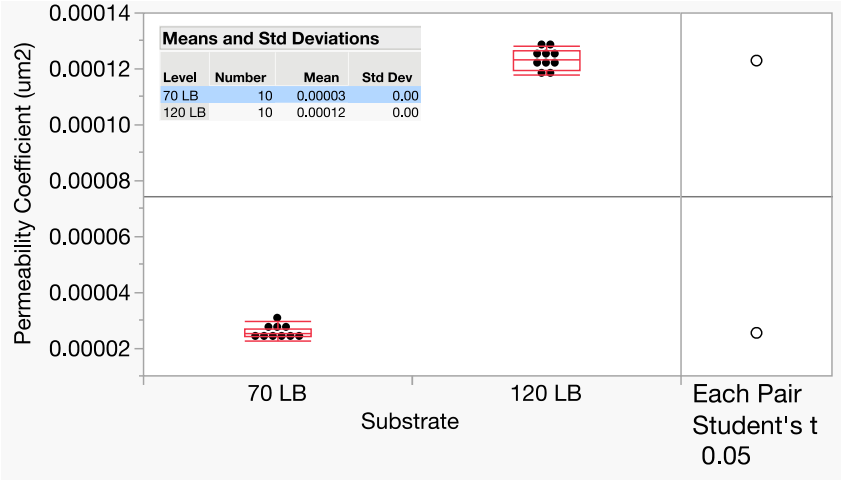
Substrate characterization

- 120 LB is **thicker**, **rougher**, and **more permeable** than 70 LB
- 70 LB has **lower air permeance and permeability coefficient**, indicating a **denser structure**.

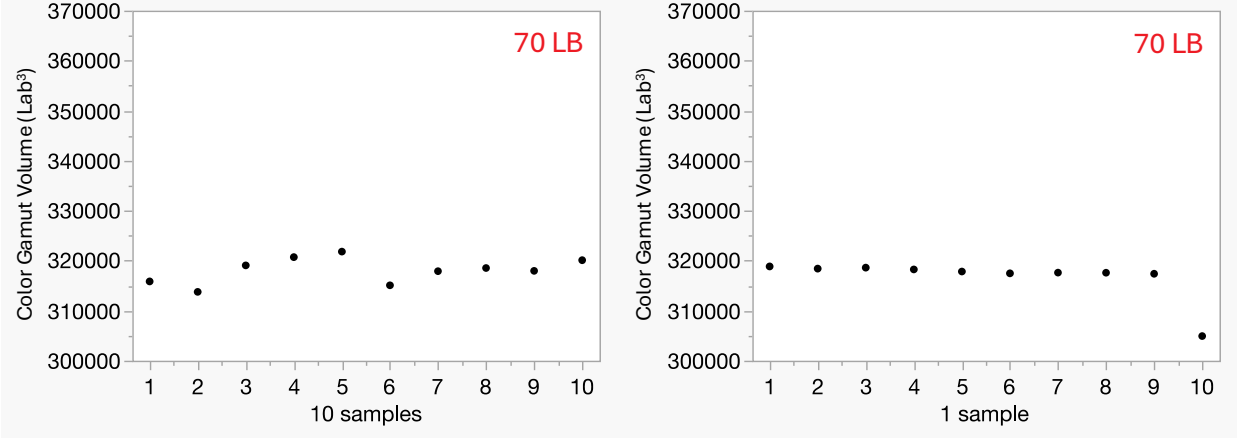




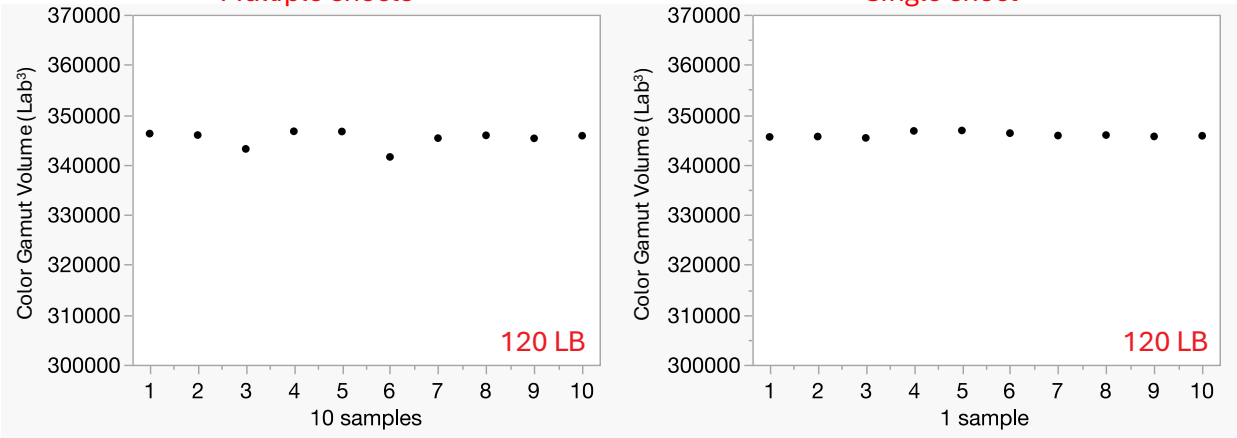




iSis 2 XL

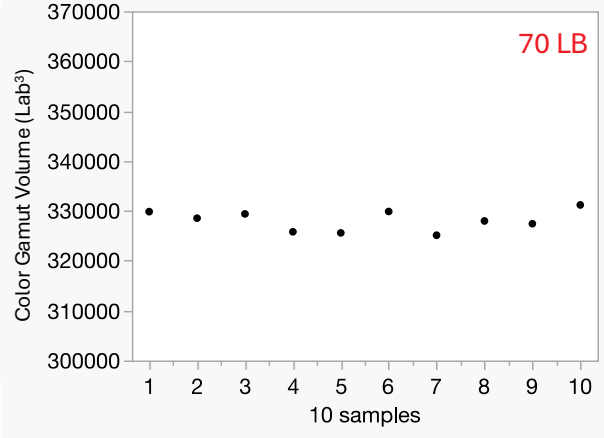


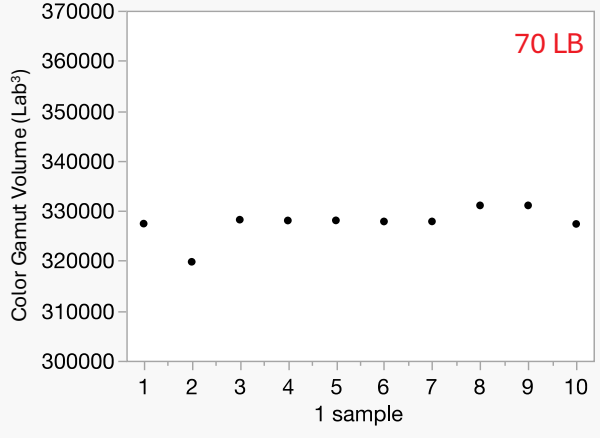
Multiple sheets



Single sheet

i1iO 3





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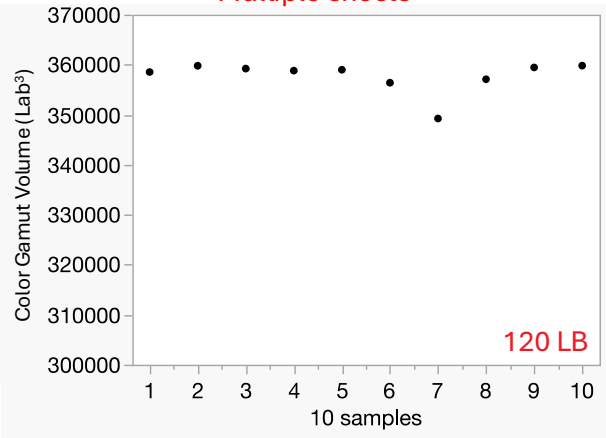
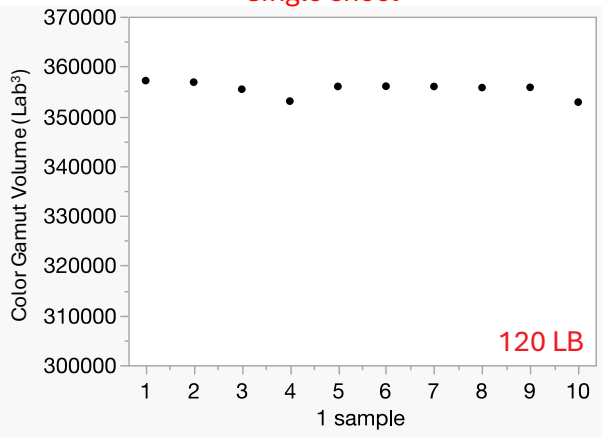
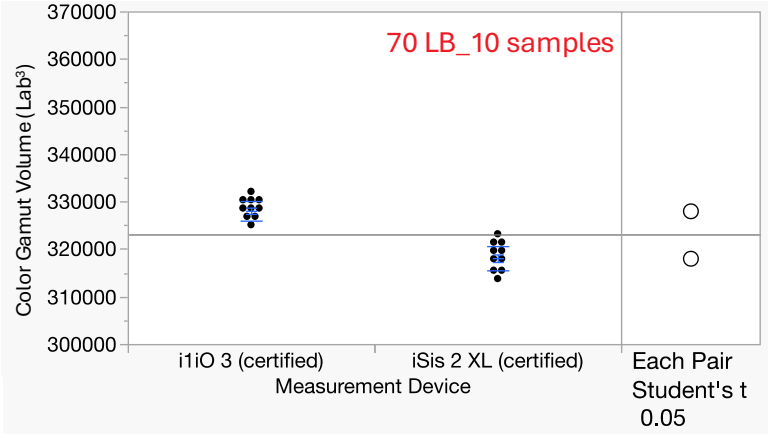


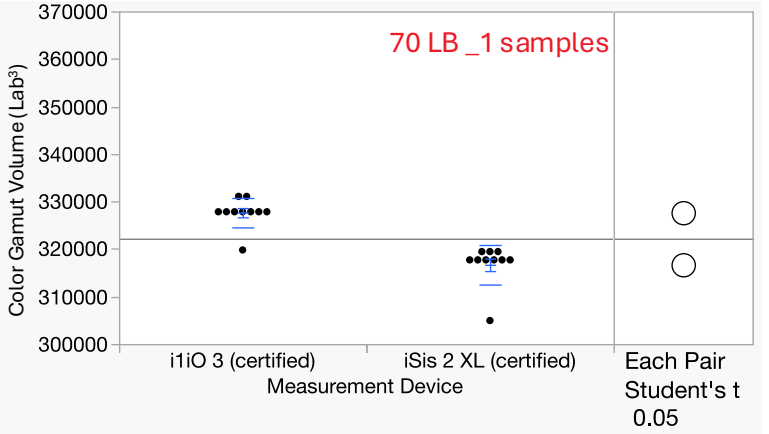
Single sheet



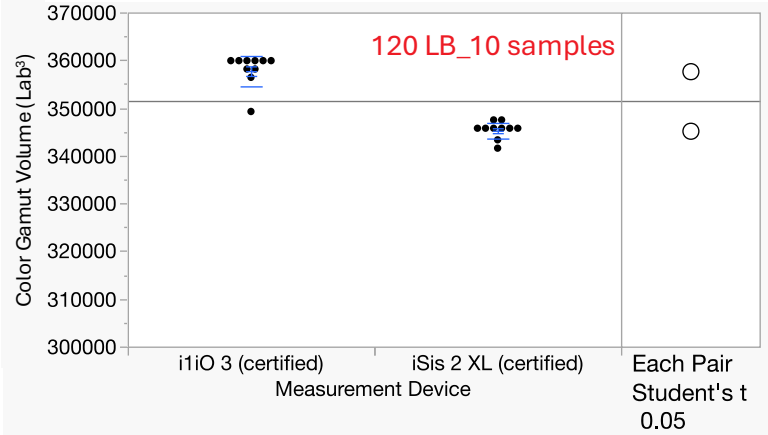
i1iO 3 vs. iSis 2 XL

- **i1iO 3 consistently measured a higher CGV** than iSis 2 XL
- The color gamut volume difference between the measurement devices is **statistically significant**, highlighting the importance of device selection when evaluating or comparing printed output.

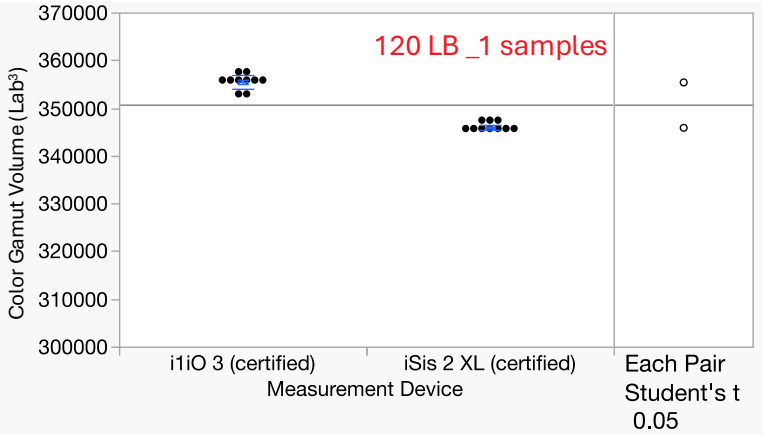




Multiple sheets



Single sheet



Single vs. multiple measurement

- Across both substrates, the **i1iO 3 consistently reports higher CGV values than the iSis 2 XL**, in both maximum and average measurements.
- The differences between **10-sample averages** and **1-sample values** are relatively small, indicating that both devices provide **consistent measurements** across repeated trials.
    - However, slight variation still exists, emphasizing the value of multi-sample averaging for more reliable color characterization

Maximum	70 LB		120 LB	
	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	346,838
Δ	9,368	12,211	13,123	10,298

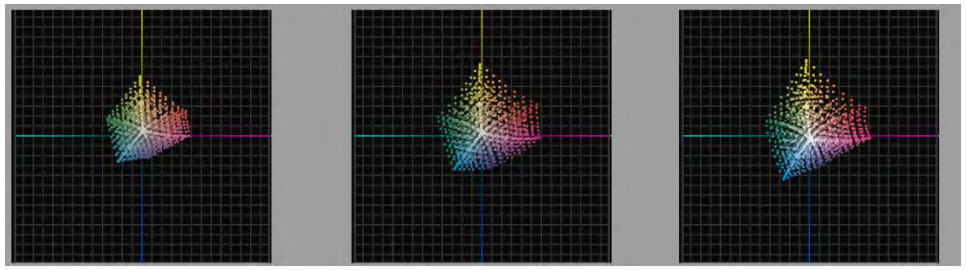
Average	70 LB		120 LB	
	10 samples	1 sample	10 samples	1 sample
i1iO 3	328,056	327,663	357,720	355,468
iSis 2 XL	318,077	316,692	345,237	345,958
Δ	9,979	10,971	12,483	9,510

CGATS reference printing

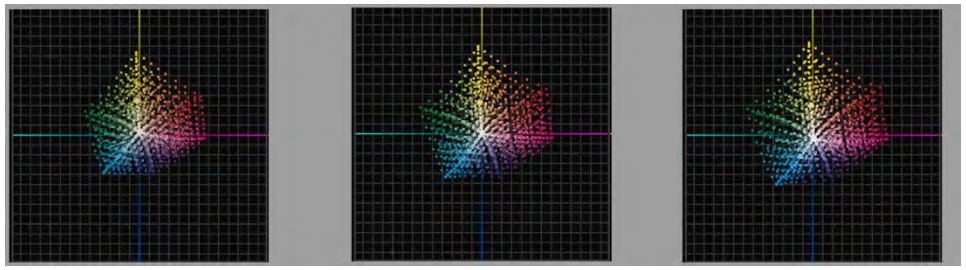
- Relative color gamut volumes of CRPCs 1 through 7

CGATS21	Color Gamut Volume* (Lab^3)	
CRPC1	84,269	
CRPC2	151,437	Δ 67,168
CRPC3	165,741	Δ 14,304
CRPC4	253,676	Δ 87,935
CRPC5	331,355	Δ 77,679
CRPC6	388,960	Δ 57,605
CRPC7	525,469	Δ136,509

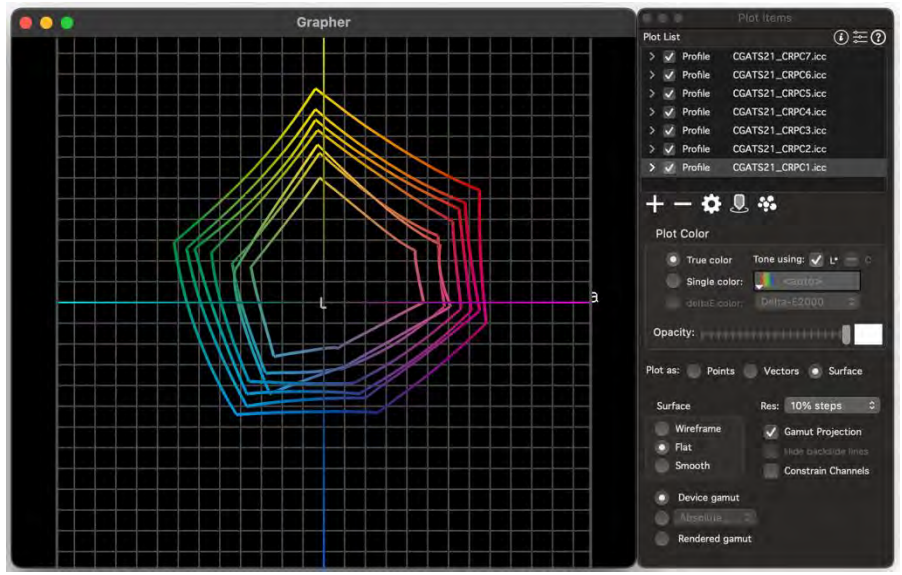
ColorThink Pro 3.0,9 (Windows)



1 – cold-set news | 2 – heat-set news | 3 – quality uncoated



4 – pub super-calendared | 5 – pub coated | 6 – commercial coated | 7 – generic large gamut



Pairwise Colorimetric Patch Comparisons: Single Target Measured 10x

	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	1,617	72,765						

Pairwise Single 70# iSis $\Delta E_{ab} > 1.0$

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							

Pairwise Single 120# iSis $\Delta E_{ab} > 1.0$

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	O12	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							

Single 70# ΔE_{ab} Pairwise Comparison with i1iO

- Unique Circumstance among tested substrates/instruments
  - Out of 72,765
    - 1,257 exhibited a $\Delta E_{ab} > 1.0$
    - 89 exhibited a $\Delta E_{ab} > 2.0$

Pairwise Single 70# i1iO 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	10.50	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	

Pairwise Single 120# i1iO $\Delta E_{ab} > 1.0$

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							

Reported Instrument Accuracy

X-Rite i1

- i1 Pro 3
  - Average 0.3 ΔE_{00} on 12 BCRA (CCSII) Tiles
  - 0.8 ΔE_{00} MAX
- i1 iSis 2XL
  - Average 0.4 ΔE_{00} on 12 BCRA (CCSII) Tiles
  - No reported MAX

X-Rite Handhelds

- X-Rite eXact
  - Average 0.25 ΔE_{ab} on 12 BCRA (CCSII) Tiles
  - 0.45 ΔE_{ab} MAX (M0, M1, M2)
    - 0.55 ΔE_{ab} MAX (M3)

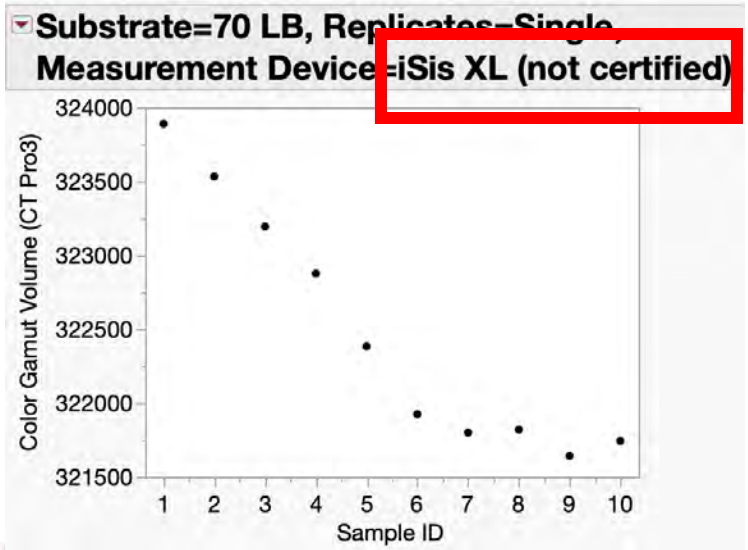
Conclusions, Implications, & Future Studies

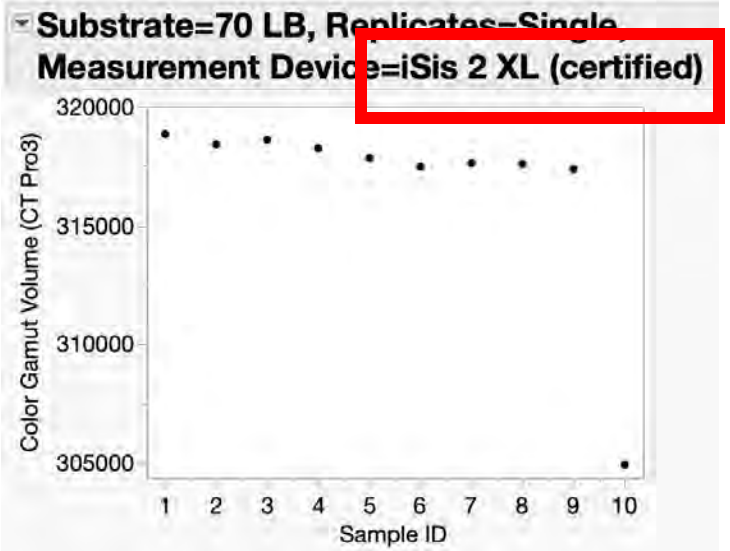
Conclusions

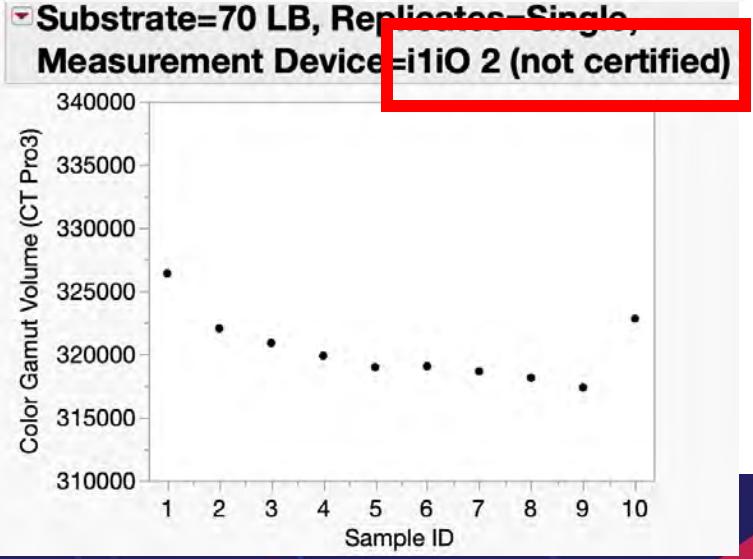
- Calculation of CGV is replete with variables
- Clinical importance of CGV differences is unclear
- There is no evidence that tested color measurement instruments underperform their tasks based on reasonable expectations with CGV calculations
  - Pairwise comparisons of colorimetric values exhibits differences, but has minimal impact on resulting CGV
  - x, y positioning of automated patch readings likely contributor to variance
  - With the i1 iSis, darker colors (L* < 50) seemingly more likely to exhibit higher differences with pairwise comparisons

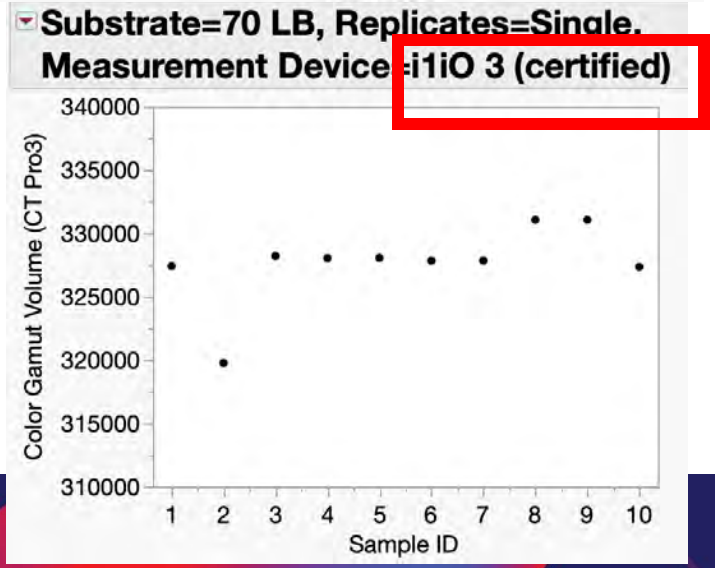
Uncertified vs Certified

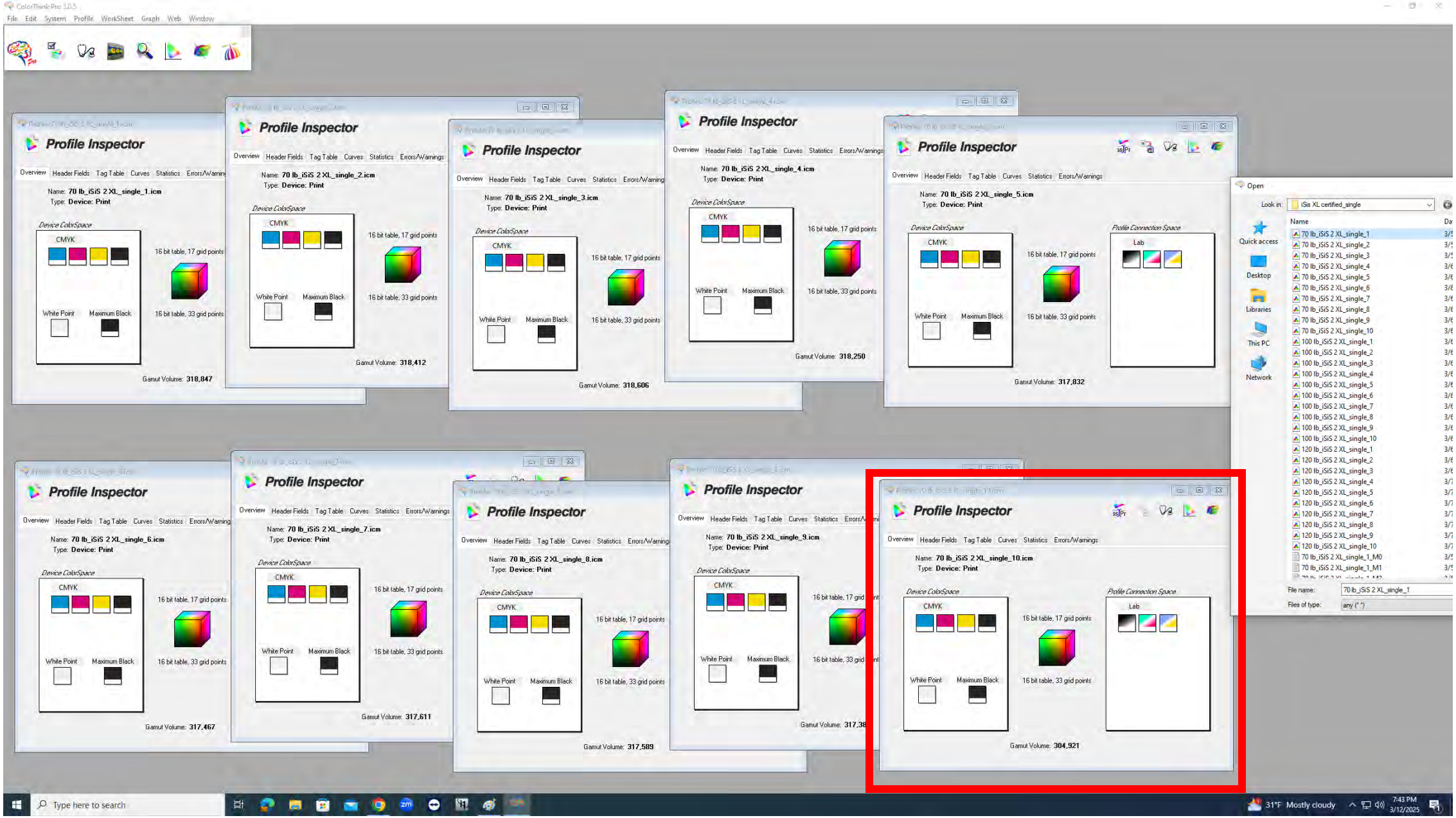
- Gradual CGV decrease observed with uncertified measurement devices
  - Importance of certified instrument (different versions, different optics)







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Profile Inspector
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CMYK
White Point Maximum Black
16 bit table, 17 grid points
16 bit table, 33 grid points
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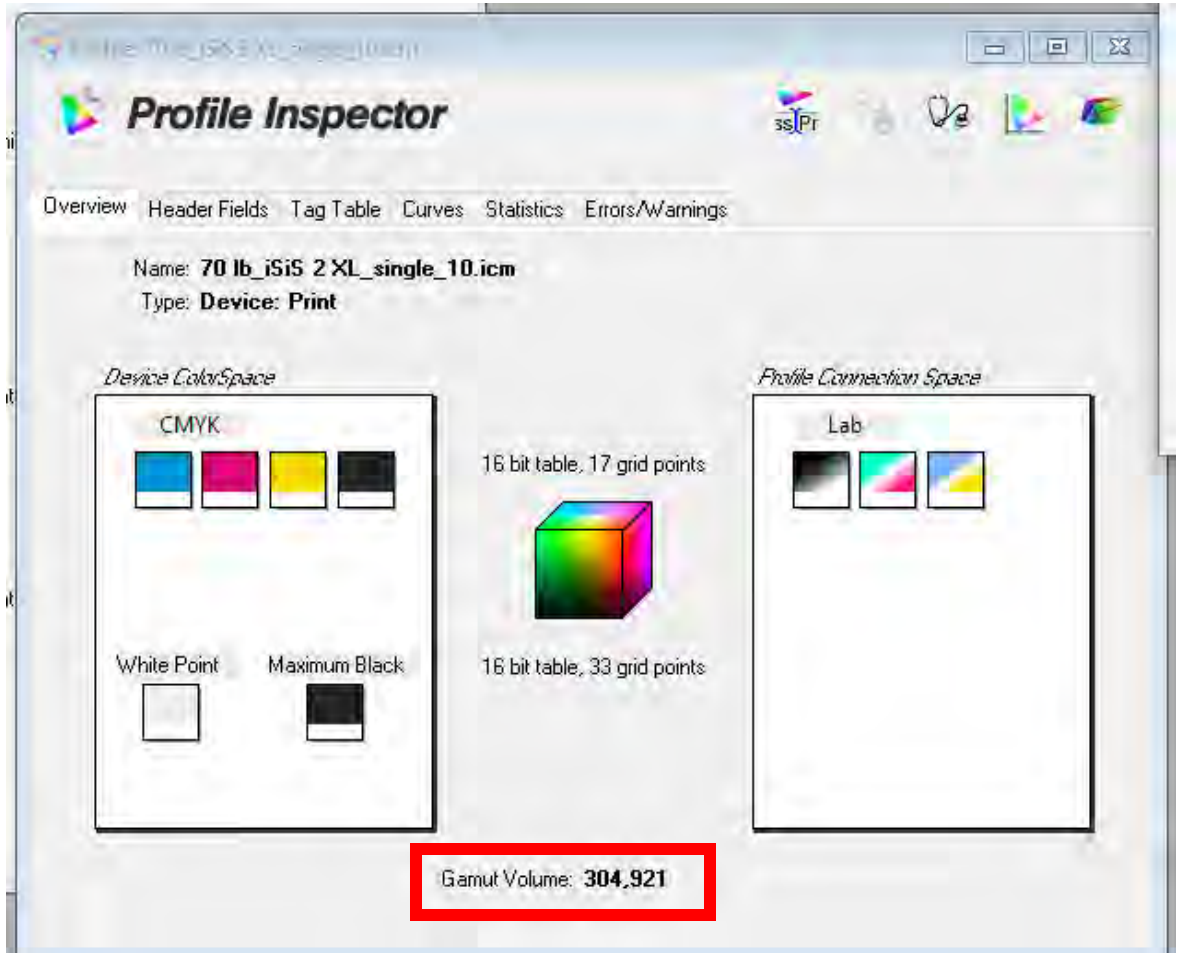
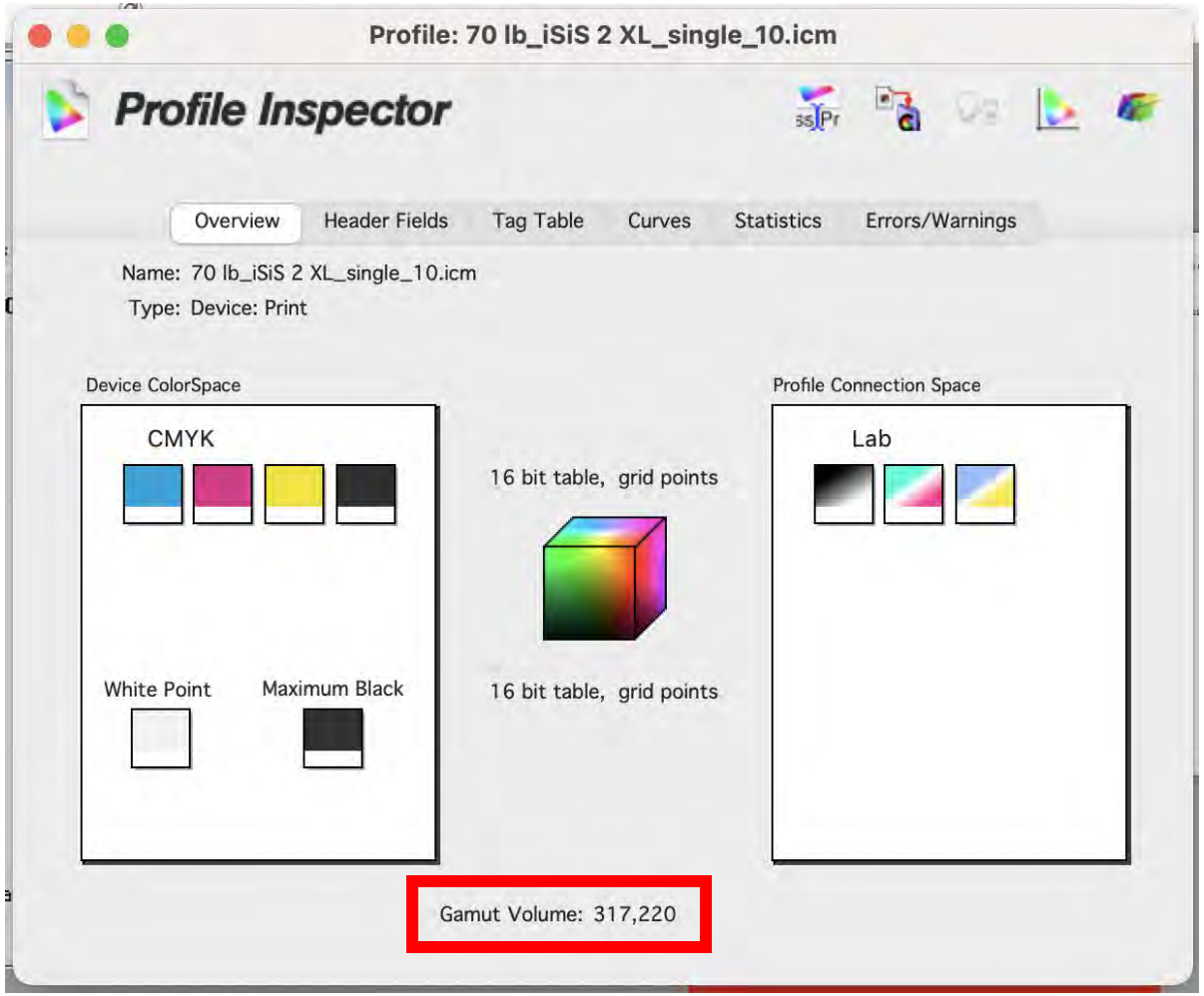
3/12/2025

Windows

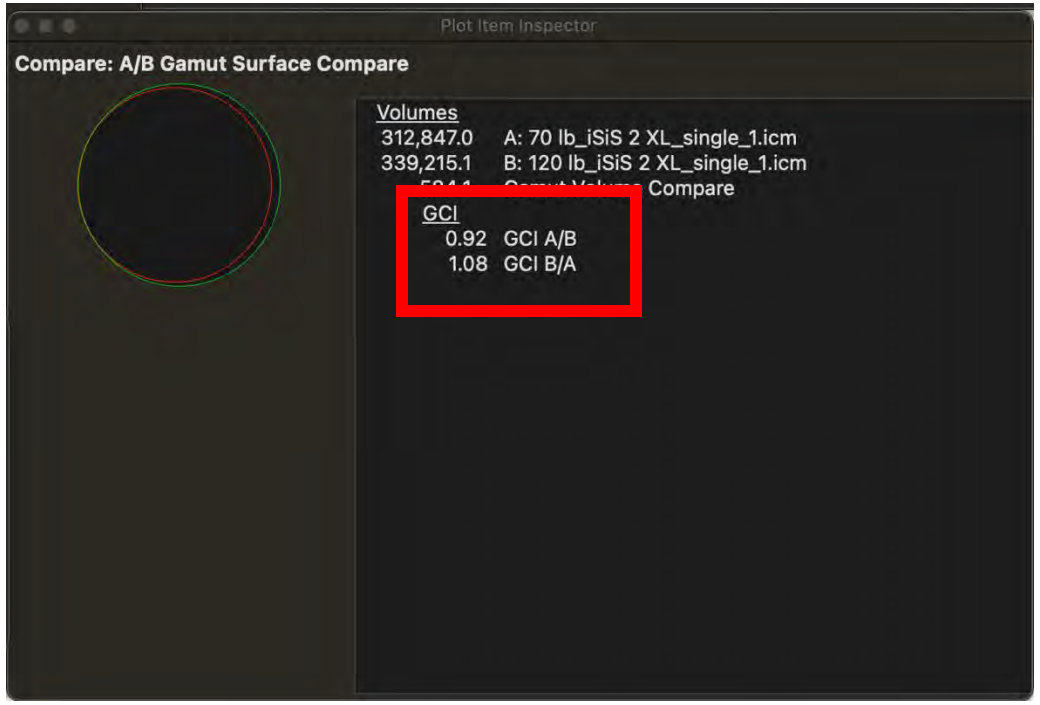


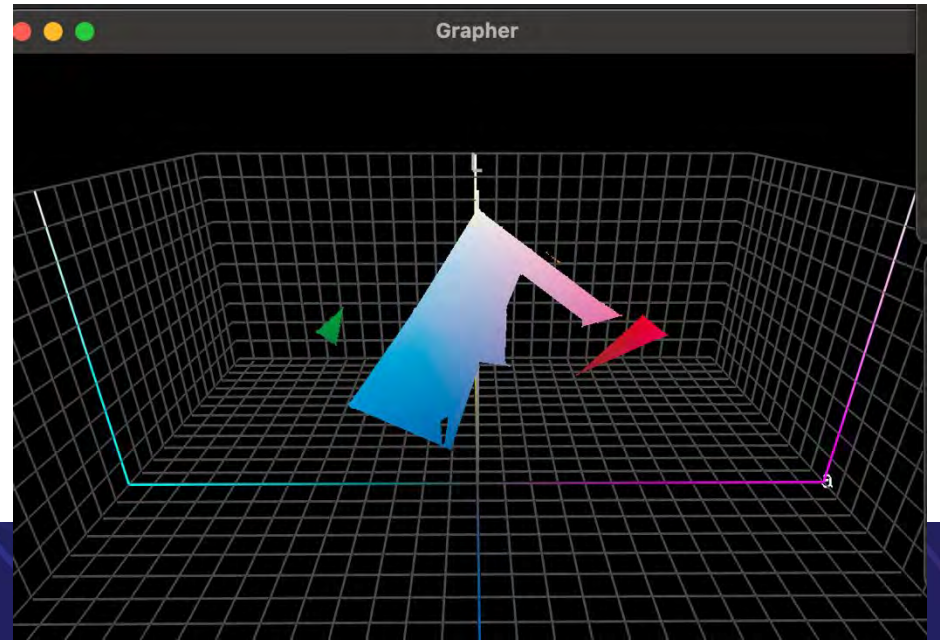
MAC OS



Implications

- Certified instruments are required
- Researchers and consumers
  - Substrate Qualities
  - Averaging
  - Reporting instrument, software, and OS
  - Gamut Comparison Index (GCI)





Future Research

- Future researchers should report more than simple gamut volumes
  - Software & Operating System
  - Instrument
  - Procedures
  - Averaging
  - Substrate characteristics
- Multi-Sampling Averaging Advised
  - The reason for appendices

Future Studies

- Clinical importance of CGV differences
  - Psychophysical studies
- Different automated instruments
  - e.g., Barbieri, Konica Minolta Sensing
  - Handheld instruments
    - e.g., X-Rite eXact, Techkon Spectrodens, Konica Minolta FD-7
- Data Collection of Substrate Alone?
- Different printing technologies
- One test chart design to be able to read across platforms

Thank you for your support

- We are grateful for the organizations that support our curriculum and research

Questions?

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