Visually Assessing Maize Leaves: From Spectral Sampling to High-Fidelity Color Reproduction

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Outline

- ❑ Introduction
- ❑ Methodology
- ❑ Results and Discussion
- ❑ Conclusion

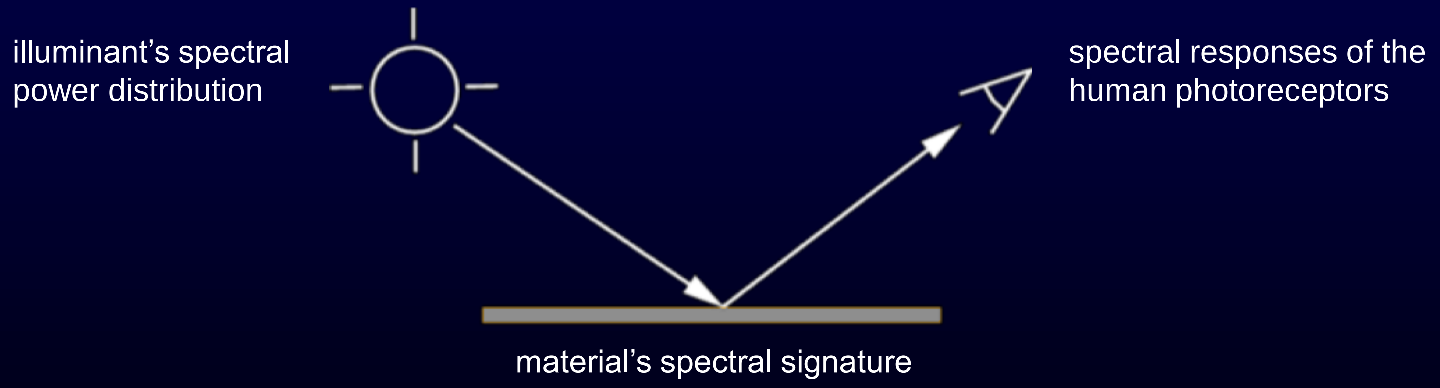
Introduction

➢ Context

- Maize (corn) crops are extensively used in food and biofuel production worldwide

- A number of protocols have been proposed to use leaf color as an indicator of biophysical phenomena affecting these plants’ physiology and appearance
- Several vegetation indices, employing leaf’s reflectance and transmittance samples, have also been formulated to monitor the development of these plants

- Pros and cons of each strategy
  - The complexity of the color perception process can make the correct interpretation of a leaf’s chromatic attributes a difficult task



- Spectral vegetation indices:
    - are not subject to color perception issues (*e.g.*, metamerisms)
    - require a number of spectral samples obtained using specialized sensors
    - are usually formulated to assess specific conditions affecting the plants

- The visual feedback provided by foliar chromatic attributes allows for a rapid screening of the net effect of several factors affecting a plant

- How about the combined used of indices and color-based strategies?

  - Leaf chromatic attributes can be obtained using spectral reflectance and transmittance samples employed in the computation of vegetation indices

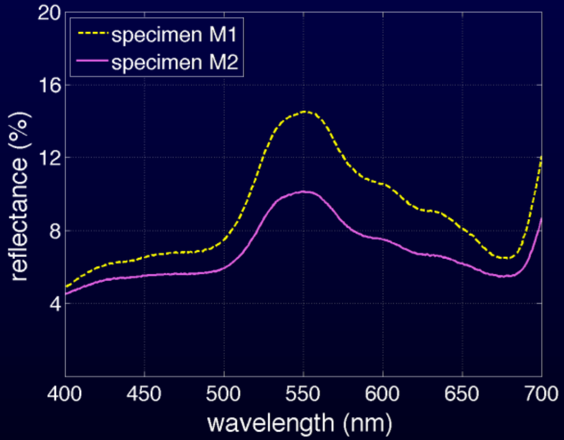
  - Ideally, one would like to employ a number of spectral samples that would maximize the color fidelity to sensor costs ratio

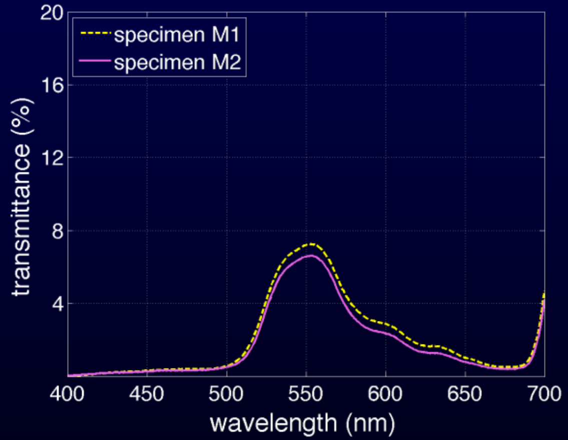
- How many spectral reflectance and transmittance samples would be sufficient to obtain a high-fidelity reproduction of maize leaves' colors?

Methodology

➢ Materials

- Specimens (M1 and M2) with measured spectral reflectance and transmittance curves made available in the LOPEX (Leaf Optical Experiments 1993) database

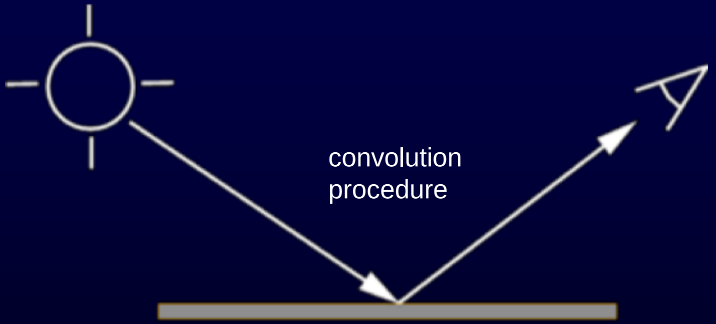




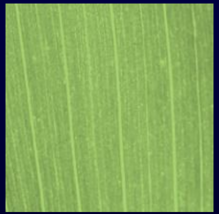
angle of incidence of 8 degrees

➢ Approach

- Computation of maize leaves’ chromatic attributes considering distinct light interaction scenarios and sparse spectral sampling resolutions



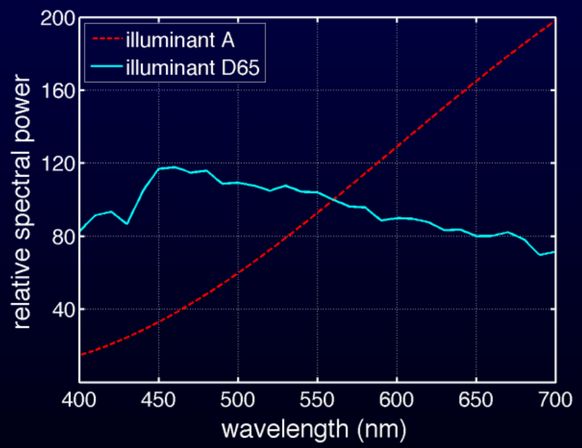
→ CIE XYZ → sRGB →



leaf swatch

- Visual inspection of colored swatches (generated using the computed attributes)
- Assessment of their color fidelity using a device independent CIE-based metric

- Light interaction variables
  - Specimens’ light propagation behaviours
    - Reflected light only (*e.g.*, leaf over an opaque surface)
    - Reflected and transmitted light
  - Indoors and outdoors illumination settings
    - Standard CIE A illuminant (tungsten lamp)
    - Standard CIE D65 illuminant (average daylight)



Selected spectral resolutions

- Illuminants' spectral power curves and specimens' spectral reflectance and transmittance curves are sampled using the same spectral intervals

N	Spectral Intervals	Sampled Wavelengths
3	Variable	465, 551 and 608 nm (monitor chromaticities)
5	75 nm	400, 475, 550, 625 and 700 nm
6	60 nm	400, 460, 520, 580, 640 and 700 nm
7	50 nm	400, 450, 500, 550, 600, 650 and 700 nm
8	37 nm	400, 437, 474, 511, 548, 585, 622, 659 and 696 nm
301	1 nm	all from 400 to 700 nm (full spectral resolution)

- Standard monitor chromaticy coordinates are used for comparison purposes
- Full spectral resolution (N=301) employed as a reference for fidelity assessments

- CIELAB differences between pairs of swatches computed as:

$$\Delta E^*_{ab} = \sqrt{(L^*_s - L^*_f)^2 + (a^*_s - a^*_f)^2 + (b^*_s - b^*_f)^2},$$

where:
L^*, a^* and b^* are CIELAB color space dimensions, and the subscripts s and f represent the sparse and full spectral resolutions, respectively.

Perceptibility threshold: $\Delta E^*_{ab} < 2.3$

(Source: Mahy *et al.*, 1994)

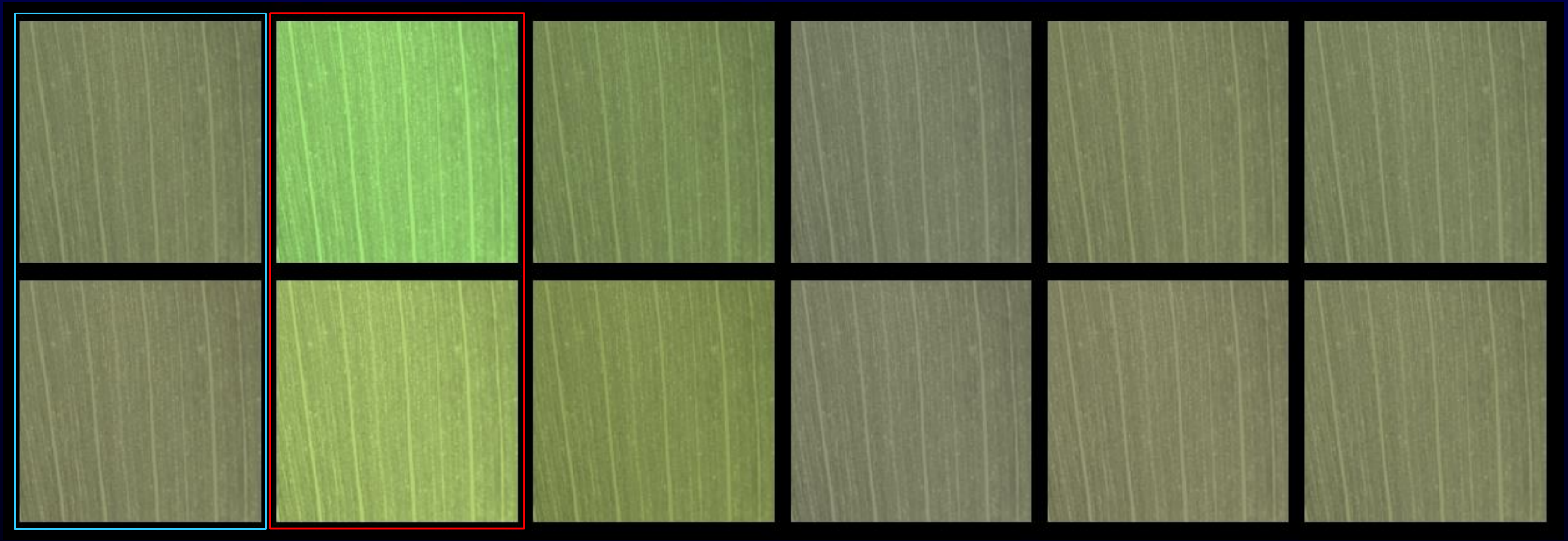
Results and Discussion

Specimen M1

- Swatches depicting foliar reflective behaviour

A

D65



$N = 301$ $N = 3$ $N = 5$ $N = 6$ $N = 7$ $N = 8$

➢ Specimen M1

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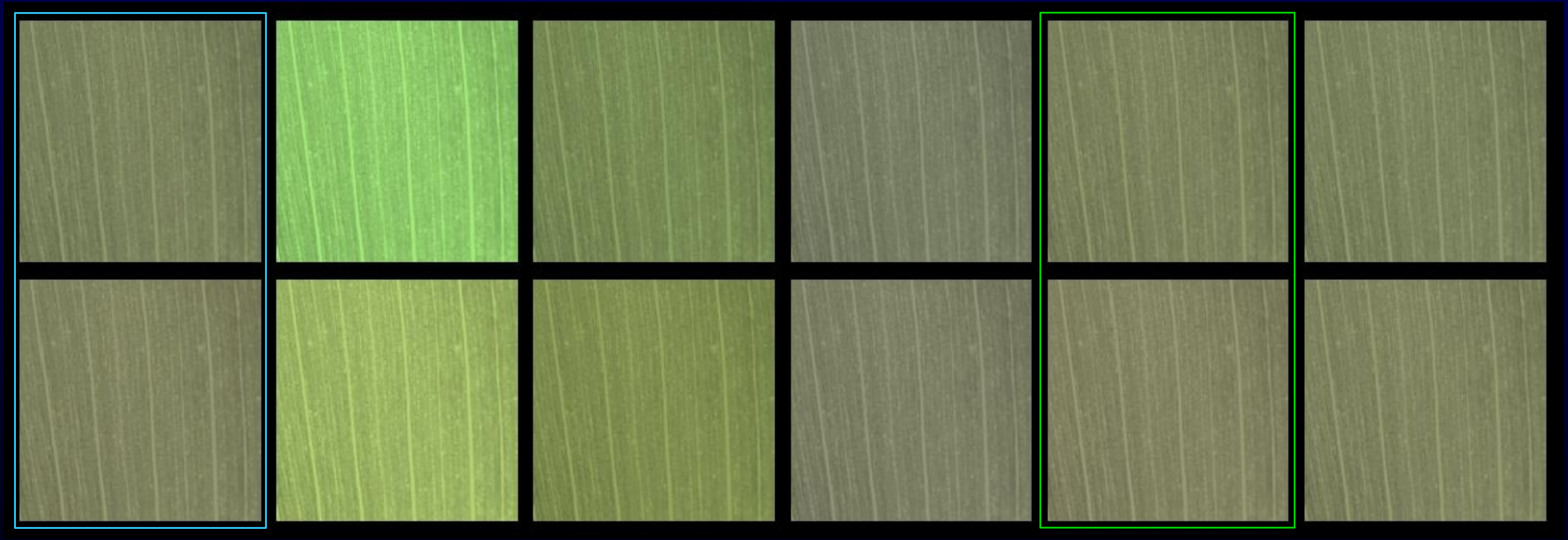

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D65

$N = 301$ $N = 3$ $N = 5$ $N = 6$ $N = 7$ $N = 8$

- CIELAB differences

	Reflective Behaviour				
Illuminant	$N = 3$	$N = 5$	$N = 6$	$N = 7$	$N = 8$
A	46.7559	11.2375	6.4528	**0.8461**	**0.8020**
D65	36.1066	19.7921	5.5571	**2.0533**	**1.3456**

  - Using 7 samples, the differences are below the perceptibility threshold (2.3)

- CIELAB differences

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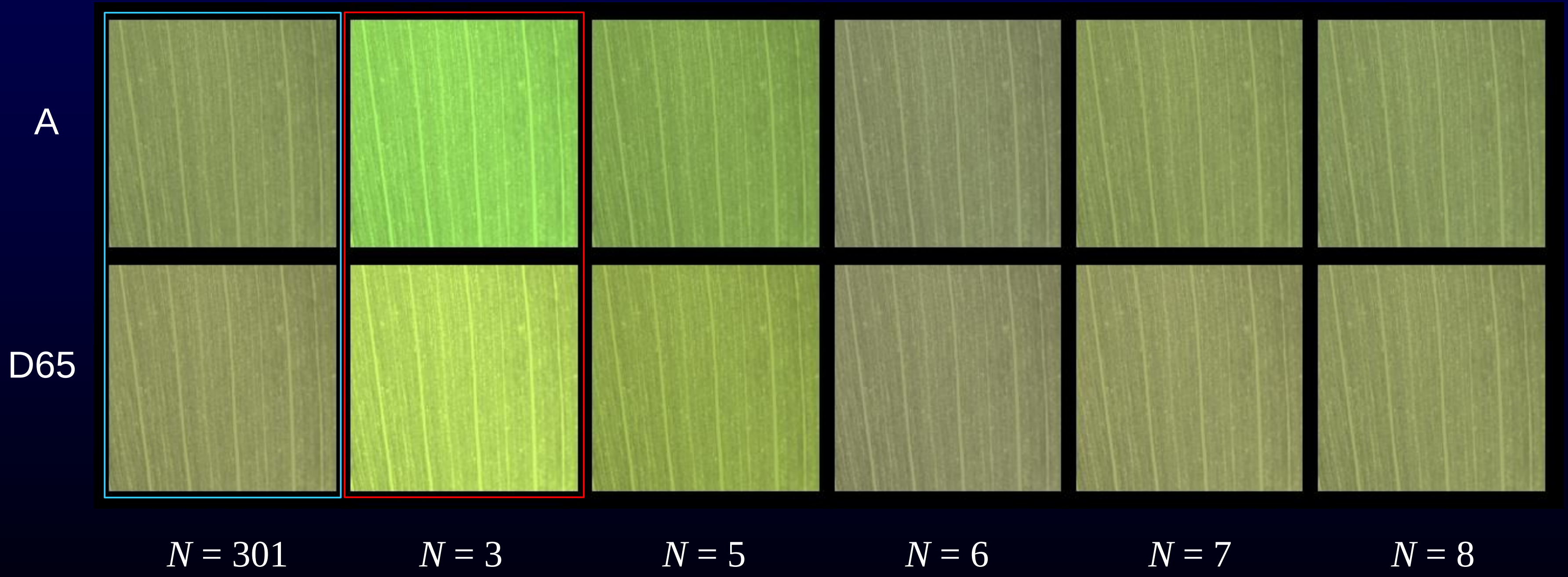
- Swatches depicting foliar aggregated reflective and transmissive behaviour



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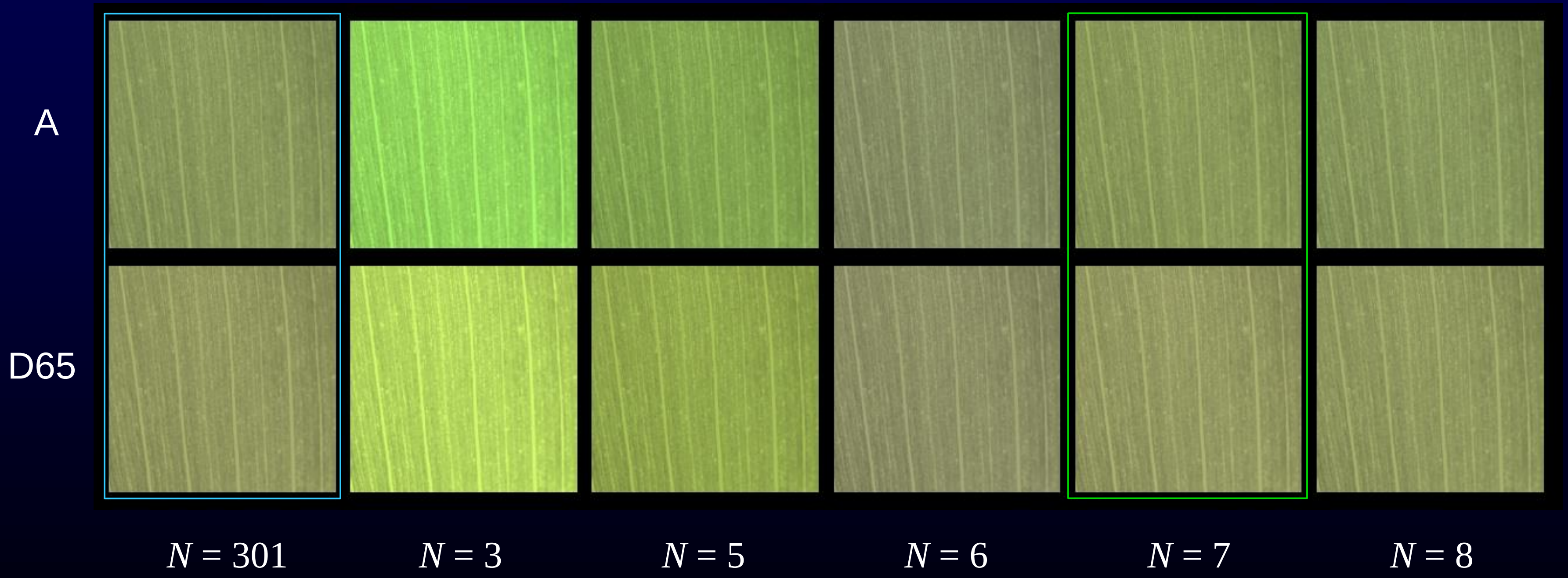

- CIELAB differences

Illuminant	Aggregated Reflective and Transmissive Behaviour				
	$N=3$	$N=5$	$N=6$	$N=7$	$N=8$
A	45.8230	17.1292	10.3191	**1.9361**	**1.1052**
D65	46.1237	25.3037	9.8280	**1.7179**	**0.8424**

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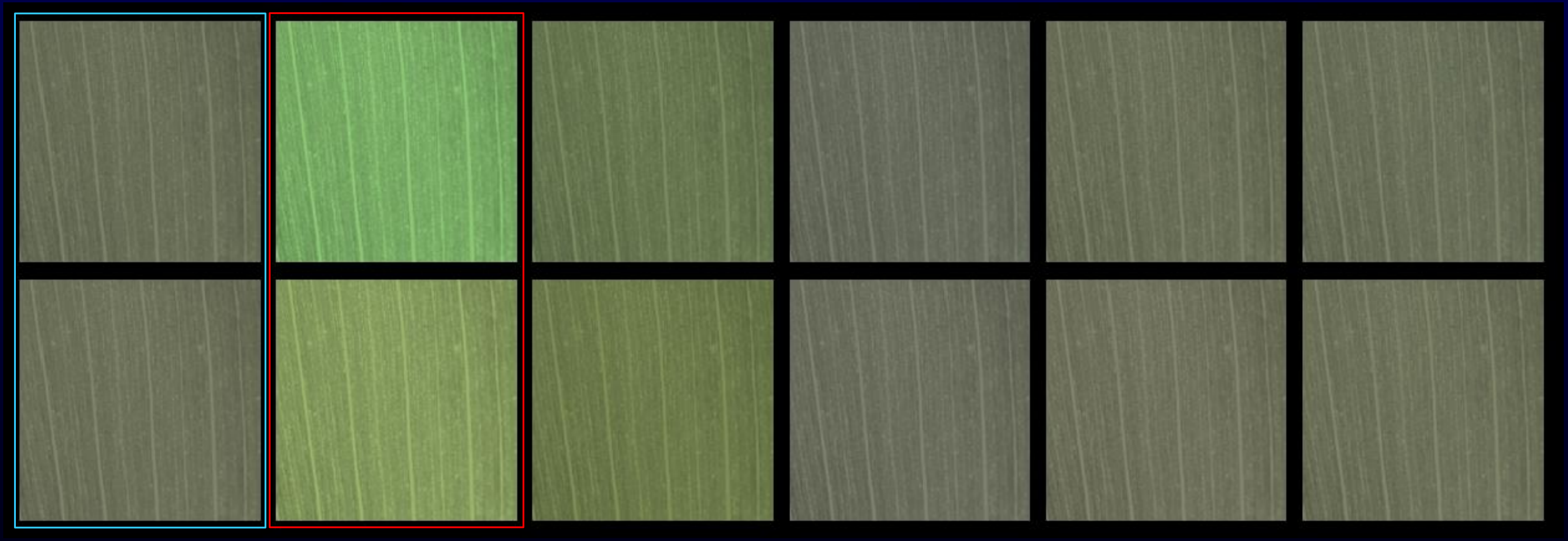
- Specimen M2

  - Swatches depicting reflective behaviour



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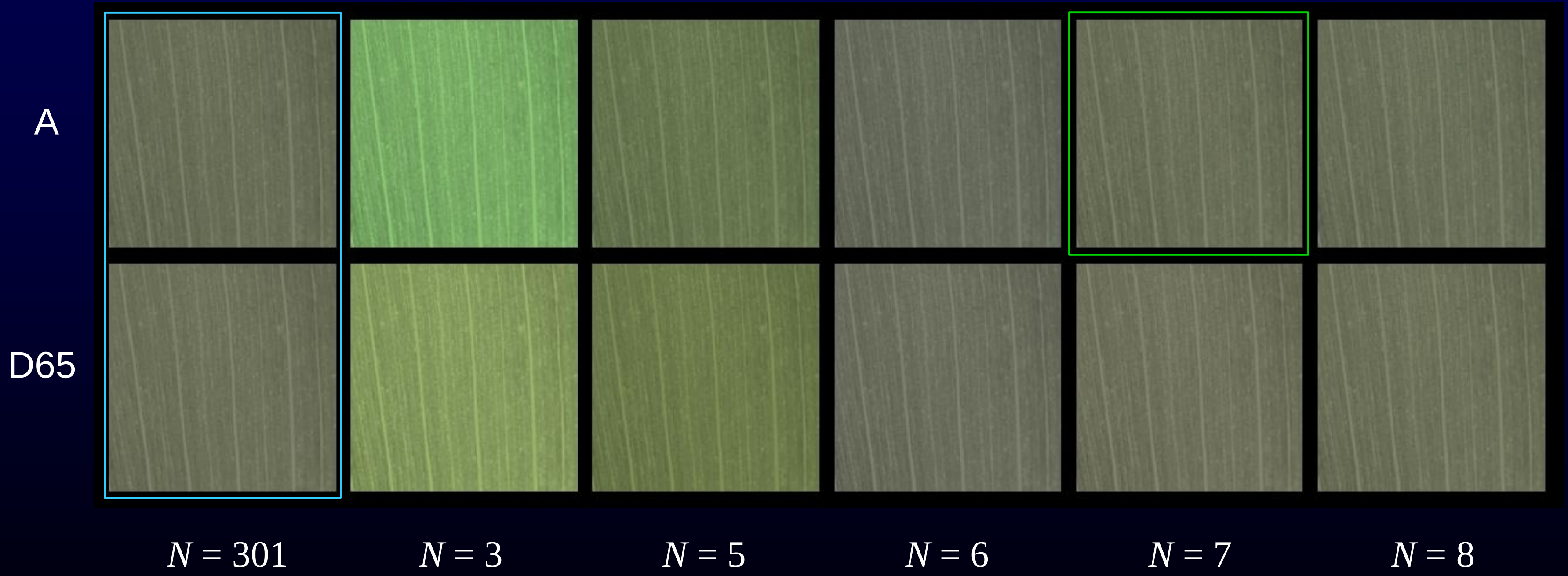

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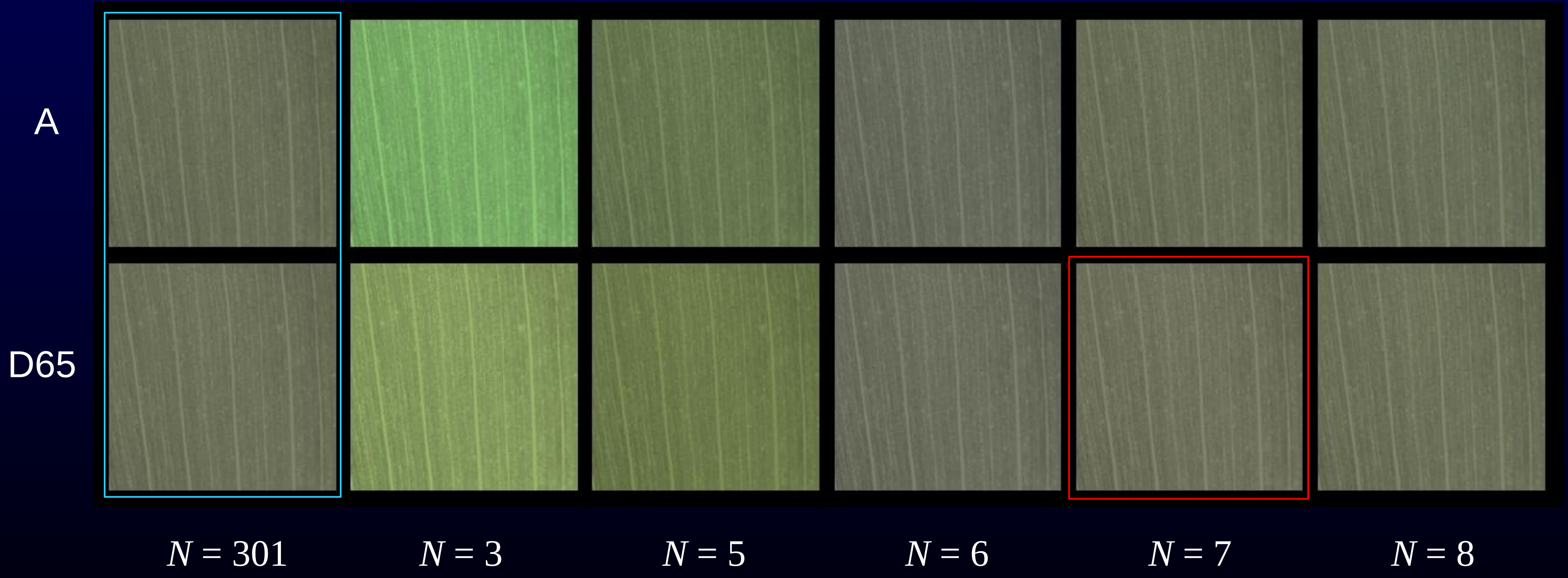

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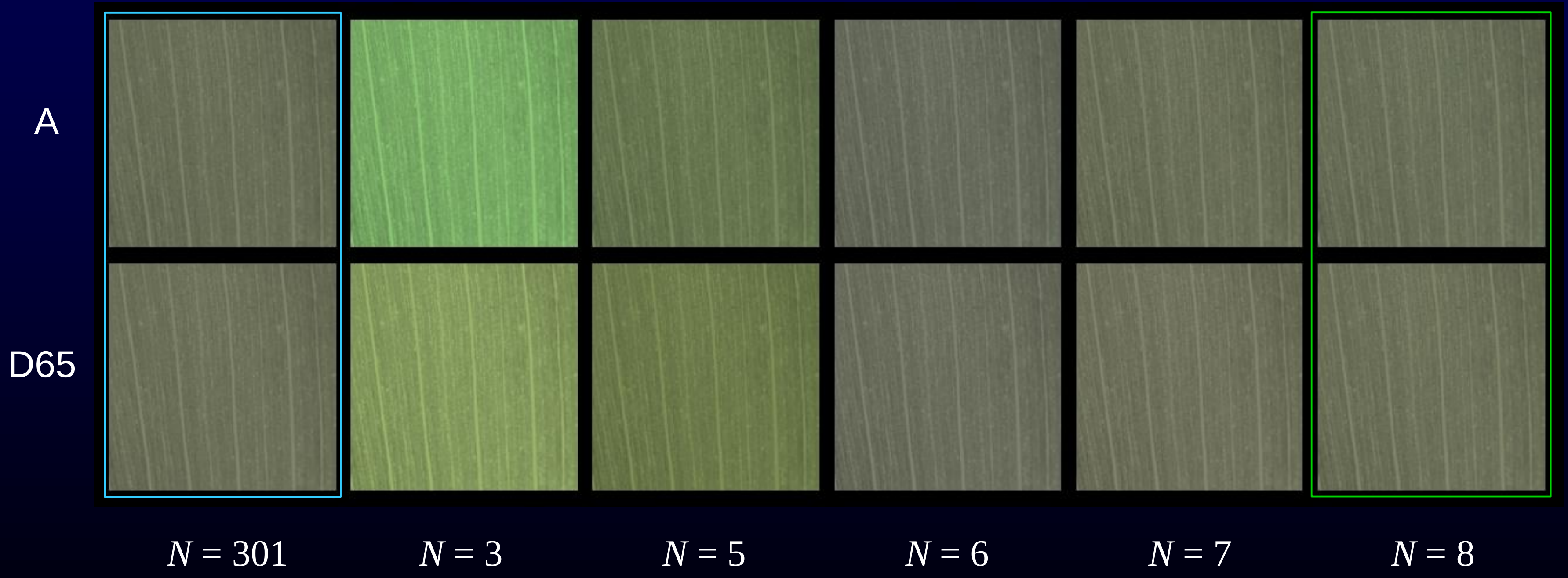

- CIELAB differences

Illuminant	Reflective Behaviour				
	$N = 3$	$N = 5$	$N = 6$	$N = 7$	$N = 8$
A	40.4986	9.7705	5.3314	**0.6346**	**0.8277**
D65	31.1737	18.0523	4.6922	2.7911	**0.7095**

  - Using 7 samples, not both differences are below the threshold (2.3)

- CIELAB differences

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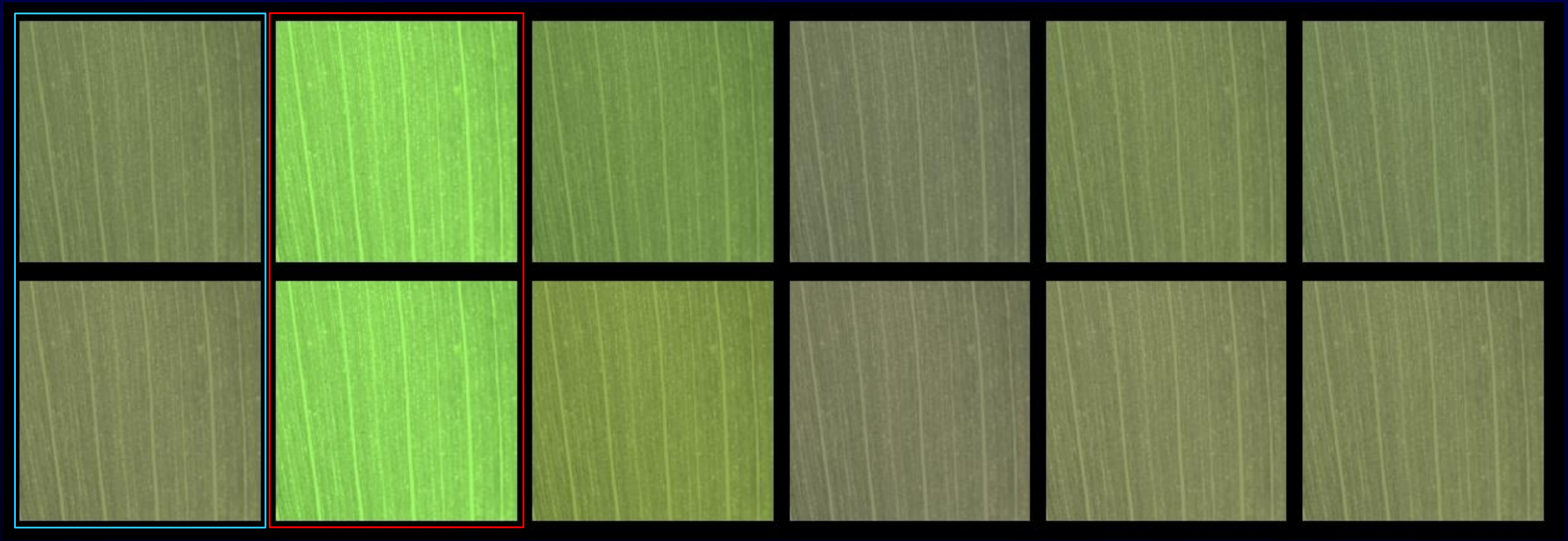

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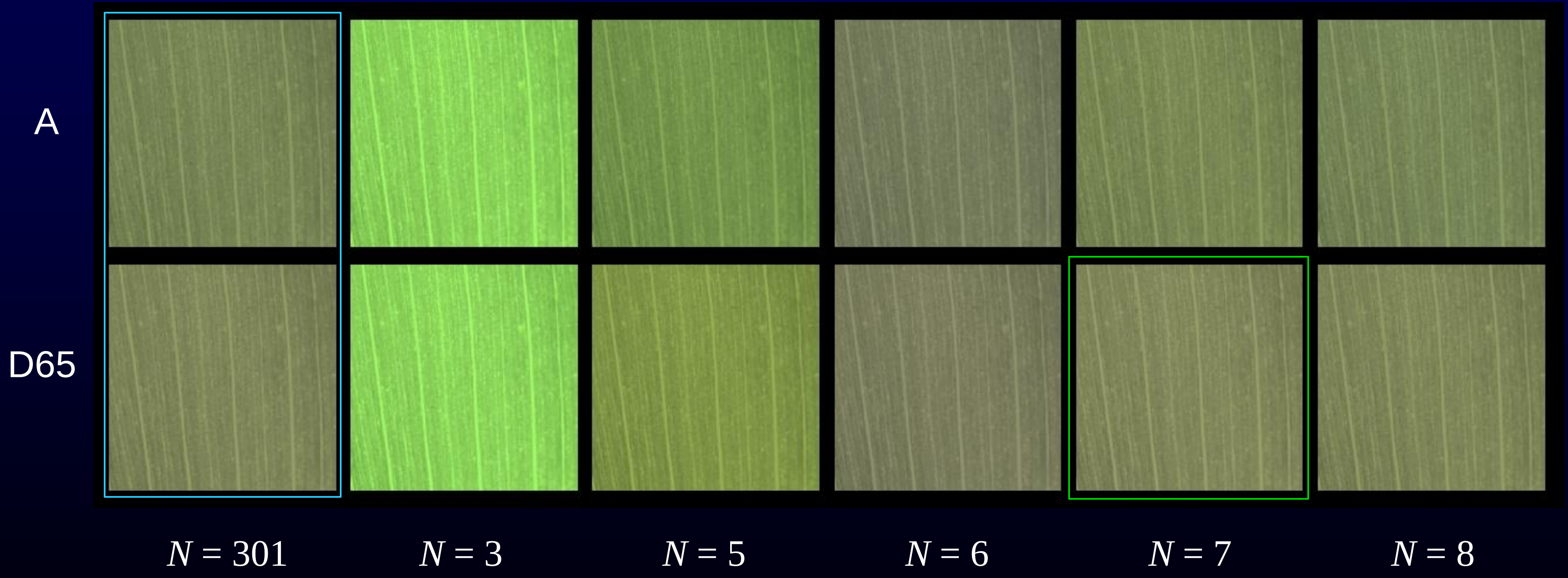

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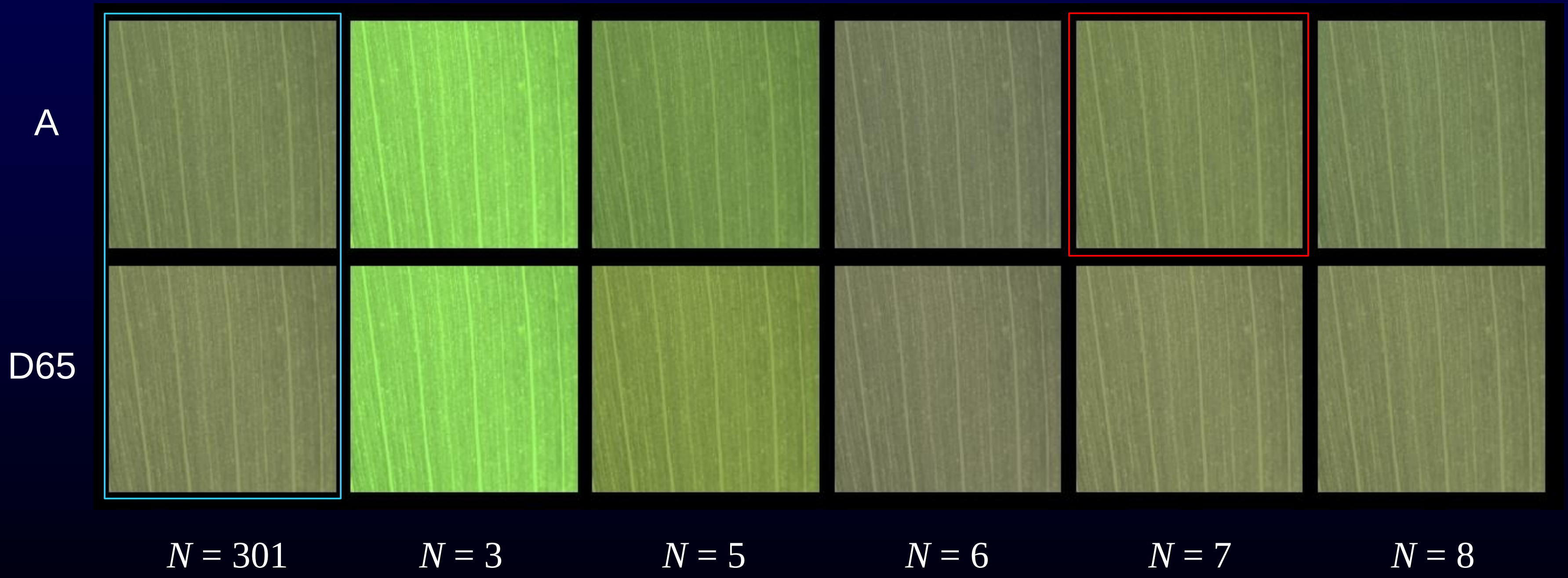

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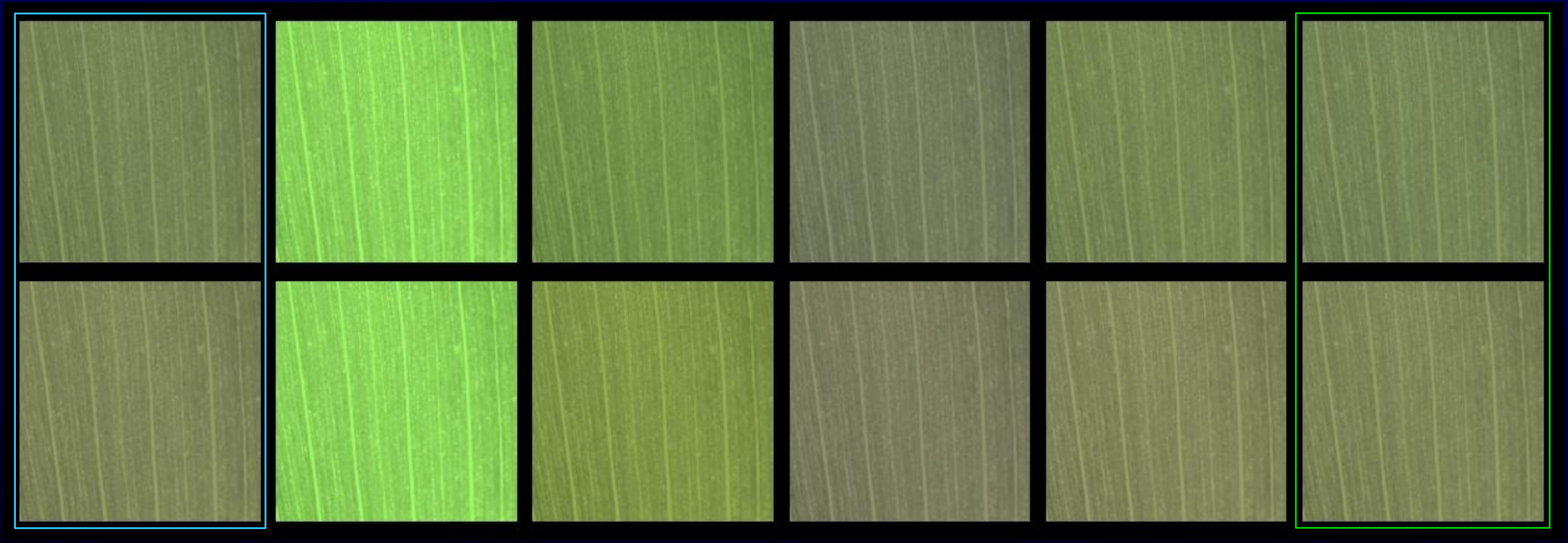

- CIELAB differences

	Aggregated Reflective and Transmissive Behaviour				
Illuminant	$N = 3$	$N = 5$	$N = 6$	$N = 7$	$N = 8$
A	53.5902	17.3101	9.9848	2.4778	**0.7864**
D65	43.4365	24.4057	9.9055	**1.4961**	**0.6757**

  - Using 7 samples, not both differences are below the threshold (2.3)

- CIELAB differences

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➢ Practical ramifications

- Our preliminary findings suggest that 8 spectral samples may be sufficient to obtain a high-fidelity reproduction of the colors of healthy maize leaves

- It may be unfeasible to find the exact number of samples that would work for:

  - all the different sampling schemes and distinct illumination/viewing geometries that could be employed in the monitoring of these plants

  - the relatively broad range of maize specimens' spectral signatures

- Nonetheless, our preliminary findings provide a basis for future experiments involving maize and other C_4 species (*e.g.*, sugarcane)

Conclusion

Recap

- Different approaches can be employed to monitor maize crops:
  - involving the calculation of spectral vegetation indices
  - involving the analysis of foliar chromatic attributes
- None can be considered the “magic bullet” capable of providing the “best” feedback for all instances
- All rely, directly or indirectly, on the interpretation of spectral signatures
- Hence, the need for more cost-effective strategies to sample those signatures

➢ Outlook

- The development of new technologies in this area will likely involve the implementation and combination of different methods

- It may be benefitial to design sensors to acquire a (low) number of spectral samples that can also be used in the creation of compact & high-fidelity leaf color databases

- These databases could potentially be extended to other C_4 species (*e.g.*, sugarcane) with similar chracteristics

Thank you!

Questions?