A close-up, top-down view of a woven basket filled with a variety of baked breads. The breads include several large bagels with poppy seeds, smaller round rolls, and braided loaves. The colors range from light golden-brown to deep, dark brown, indicating different crust textures and ingredients. The lighting is warm, highlighting the textures of the breads.

**MEASURING
CRUST COLOR WITH
HYPERSPPECTRAL
IMAGING**

specim
SPECTRAL IMAGING

Introduction

The crust color in bakery products is a good indicator of the product quality. Finding the optimal baking time and temperature reduces waste and as a result, cost.

Determining the optimal color can be a challenge. While the human eye can see colors relatively well, the results are very subjective and there is significant variation between individuals. RGB cameras color perception is significantly worse than the human eye, and the accuracy is not enough for many of the applications.

Hyperspectral instruments have the accuracy that outperforms the human eye when it comes to color measurements. Colors can be determined reliably and objectively, and the results are fully comparable.

To demonstrate how hyperspectral imaging can be used on color measurement and analysis, we measured the color of buns that all spent a different time in the oven. The baking time in the recipe was 5-6 minutes. The lightest color bun was baked for 3 minutes, the subsequent buns each one minute longer than the last one. Therefore, the darkest and clearly burned bun was baked for 8 minutes.

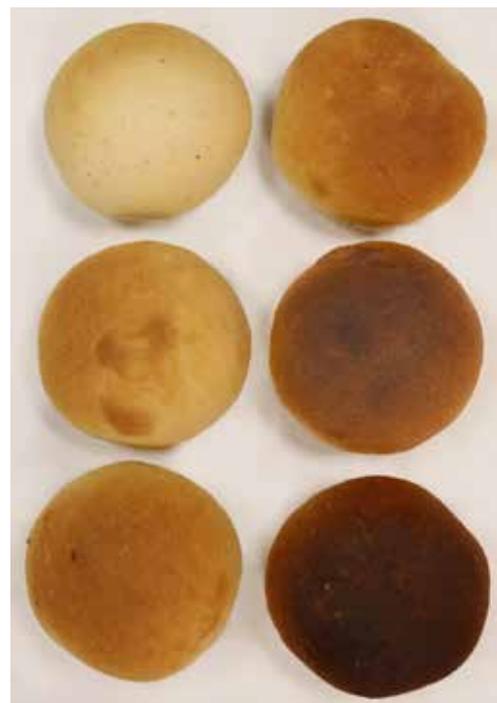


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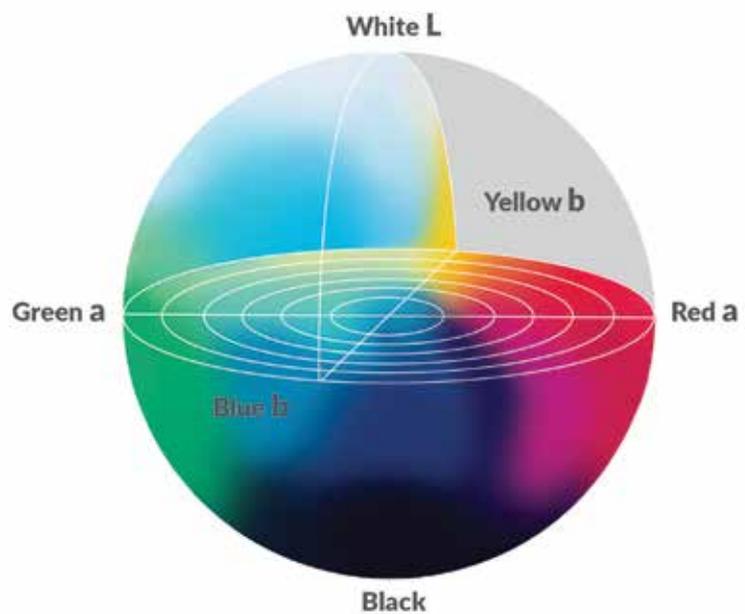
Lab color space

Hyperspectral imaging devices measure the spectra that can be analysed using the Lab color space. Lab color space is a three-axis color system, where

L = lightness, from black to white

a = from cyan to magenta/red

b = from blue to yellow



As mentioned in the introduction, RGB cameras don't even come close to the human eye when it comes to the accuracy of color perception. To indicate the color perception accuracy, we use the value ΔE . It is used to describe the difference between two points in the LAB color space. The lower the value, the more accurate the perception. Humans can achieve approximately $\Delta E=1$, while RGB cameras can only reach $\Delta E=8-10$ accuracy. Hyperspectral instruments attain $\Delta E < 1$ in absolute value, which means the color's accurate location in LAB color space. Relative value, which describes the difference between two colors in LAB color space, can be measured as closely as $\Delta E=0.2$.

INSTRUMENT	COLOR PERCEPTION ACCURACY
RGB camera	$\Delta E=8-10$
Human eye	$\Delta E \sim 1$
Hyperspectral camera	$\Delta E < 1$ (absolute) $\Delta E \sim 0.2$ (relative)

LAB colors are absolute, meaning that the color is exact and device-independent, and the results from different measurements can be reliably compared.

Test setup and measurements

We used the following equipment for testing:

- Specim FX10c
- Specim Labscanner 40x20
- 6 pcs halogen DECOSTAR 51 ALU 35W 12V 36deg GU5.3 lamps
- Data acquisition PC and Lumo Recorder SW

The measurements were done with Specim FX10c camera that operates on the visible light area (400-770 nm range). Specim FX10c has been specifically designed for color measurement.



Since the camera works with the push-broom method, and images the target line by line, the target needs to move during the measurements. In our test setup, we mounted the FX10c camera on Specim Labscanner 40x20 to create the movement. However, a scanner is not a requirement, and the movement can be achieved for example by mounting the camera over a production line.

For the adequate lighting, we used 2 rows of 3 DECOSTAR 51 ALU 35W 12V 36deg GU5.3 halogen lamps. The lights were pointed to the measurement line so that there was no shadowing on the target.

The raw data was collected using a data acquisition PC running Specim's Lumo Scanner software.



Analysis and results

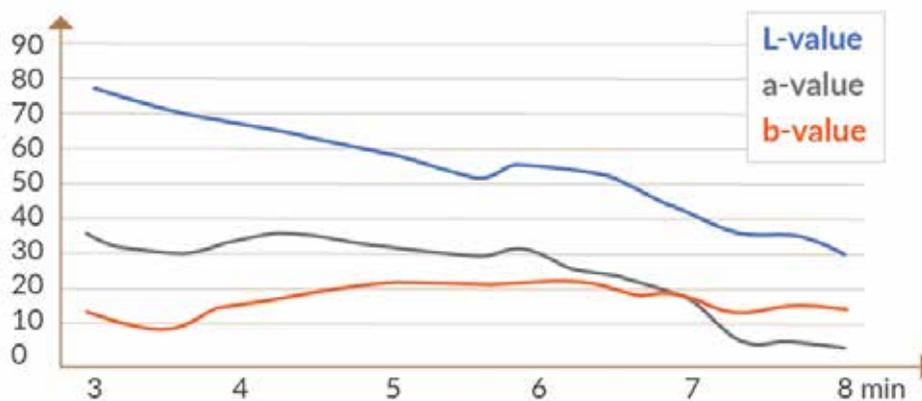
We analyzed the raw data from the samples with Specim's proprietary analysis software and got the Lab-values that define bun's crust color. For clarity, we will only present the values from three individual measurement points; however, it is possible to get these values from every single pixel of the image.

See the table below for the Lab-values measured from three different points on each bun.

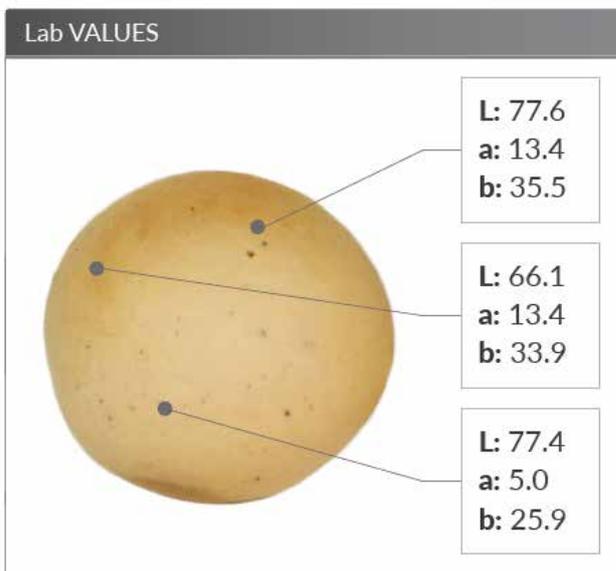
	L-value	a-value	b-value
3 min baking time	77.6	13.4	35.5
	77.4	5.0	25.9
	66.1	13.4	33.9
4 min baking time	55.6	21.3	32.3
	74.4	15.6	40.3
	55.3	21.7	28.9
5 min baking time	66.3	20.3	38.0
	51.3	19.9	28.0
	52.5	17.8	30.5
6 min baking time	59.9	22.6	31.7
	48.2	19.8	18.7
	58.4	20.3	29.0
7 min baking time	35.3	14.8	4.5
	36.7	13.9	6.8
	36.7	14.7	3.3
8 min baking time	29.9	11.9	1.4
	30	10.7	0.7
	24.8	7.5	2.6

From the analyzed data we can clearly see, that

- L- values are around 50-60 for the buns that were baked according to the recipe. Raw buns show clearly higher values (over 65) while overbaked buns' values are significantly lower, at around 35.
- A-values are lower (<16) for both undercooked and overbaked buns, the optimal values seem to be around 20-22.
- There is little difference in the b-values unless the bun is overbaked. If the b-value is <10, the bun is likely overbaked, and clearly burned if the b-value falls <4.

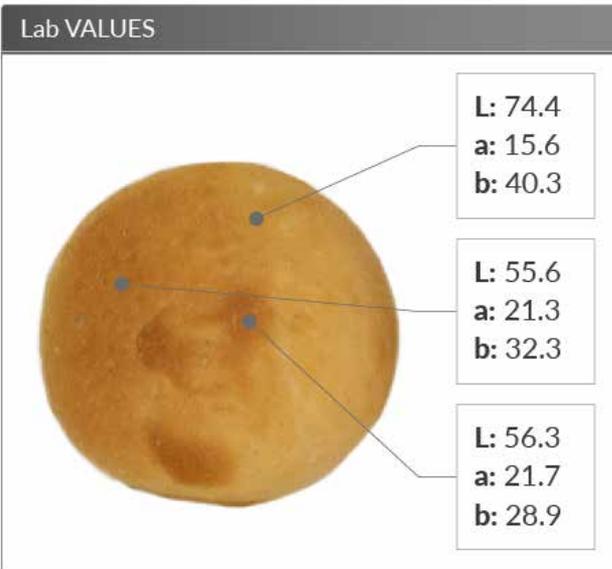


The following figures take a closer look at each of the analyzed buns.



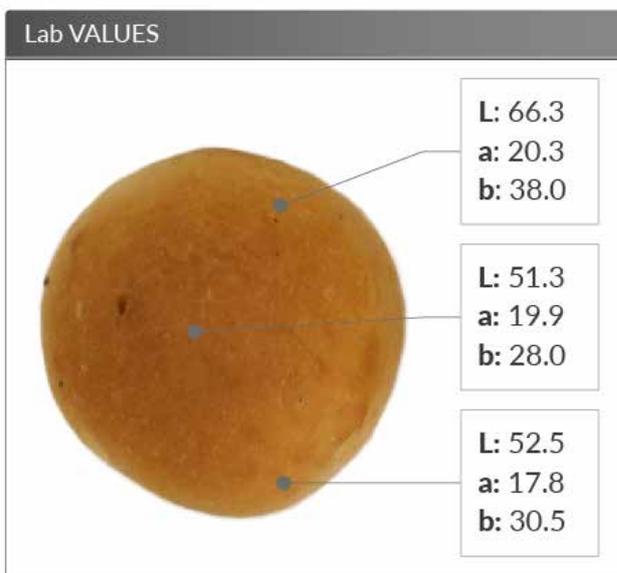
3 min baking time

L-values are consistently over 65, which indicates that the bun is too light, and the b-values are slightly higher than in the fully baked buns.



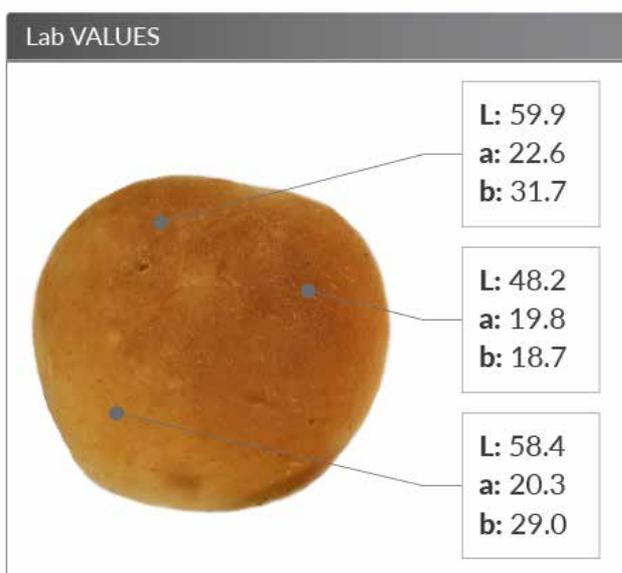
4 min baking time

Here, two of the measured points seem to give acceptable values for the crust color. However, the third measurement point indicates that the bun is not yet done: all the Lab-values in that point are closer to the undercooked 3-minute bun.



5 min baking time

This bun was baked met the baking time in the baking instructions. There are no L-values over 70, a-values are higher than both under- and overbaked buns, and b-values around 30.

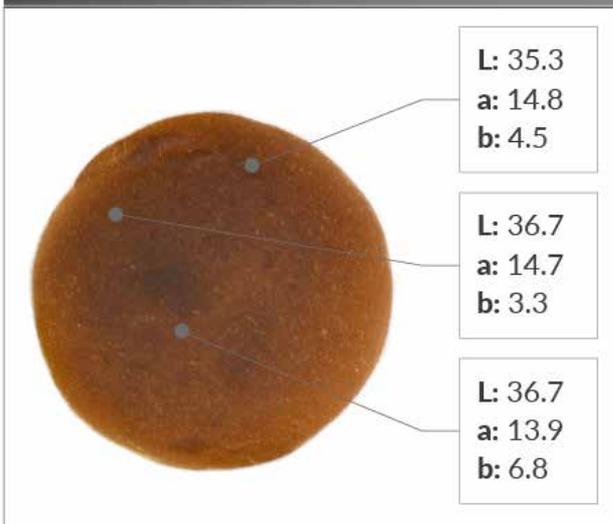


6 min baking time

While this bun is within the optimal baking time, one of the measuring points shows lower values than the 5-minute bun. This would indicate, that the baking time should be closer to 5 than 6 minutes, even though both fit into the timeframe mentioned in the baking instructions.

This shows, that to ensure that the quality is even throughout the product, it is necessary to measure as many points as possible.

Lab VALUES

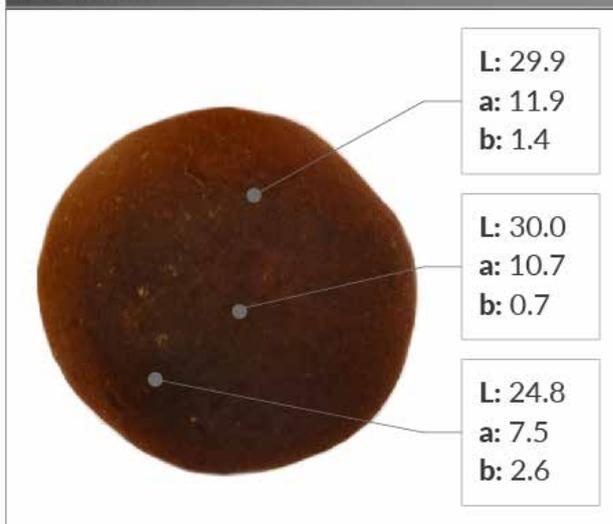


7 min baking time

In visual inspection, this bun seemed slightly overbaked, yet edible, especially when there were no other buns for reference.

All measured Lab values, however, are closer to the clearly burned 8-minute bun, clearly showing that the bun does not meet our quality criteria.

Lab VALUES



8 min baking time

The bun is clearly burned, and every point of measure is lower than the other buns we measured.

Conclusion

The hyperspectral camera is well suited for color measurements, since it is more accurate than RGB cameras and, unlike visual inspection, completely objective. It is possible to define the target's absolute color in Lab color space with the accuracy of $\Delta E < 1$ which is better than human color perception ($\Delta E = 1$), or its relative color in relation to another target as accurately as $\Delta E = 0.2$.

In the baking industry, it is possible to determine the exact crust color and adjust the baking process to improve the product quality. This will lead to a reduced amount of waste and, as a result, reduced cost. Push-broom technology makes it possible to measure every point of the target, which ensures that the product is not unevenly baked. What is more, the single line of measurement used with the push-broom method requires that only the measurement line needs to be illuminated, which reduces the amount of lighting needed.

To test the suitability of hyperspectral imaging in the baking industry, we measured buns with different baking times and crust color. Even with the small test batch, it was easy to see how baking time affected the color values. The L-values, which measure the lightness/darkness, diminished as the baking times increased. The overcooked buns also had clearly lower b-values than others. From these results, it would be quite simple to determine acceptance limits for baked goods that would help not only to sort the products based on quality but also to adjust the baking process to achieve the best results.

Hyperspectral imaging possibilities are not limited to color measurements: with this technology, it is possible to identify foreign object contamination, the amount of sugar or moisture, or to check that the filling is evenly spread, and so on. The measurements are fast and reliable, and they can significantly improve food quality and safety.



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