



Enhancing Coffee Manufacturing with Spectrophotometers for Color QC

Introduction

Global coffee production and consumption are immense, with the industry generating hundreds of billions of dollars annually. Consumer demand for consistent quality is rising: for example, 70% of coffee buyers report choosing a product only when the roast level (color) is specified. In this \$200+ billion market, even small quality lapses translate to large costs. Implementing objective color measurement throughout the coffee supply chain allows manufacturers to maintain consistent roast levels and appearance, ensuring products meet specifications every time. Spectrophotometers—devices that measure color numerically by light reflection or transmission—are key tools. They replace subjective visual grading with precise, repeatable data, minimizing waste and recall risk. This white paper explores the coffee industry and shows how spectrophotometric color QC can improve quality and ROI at every stage, highlighting HunterLab solutions and how they outperform legacy systems like Agtron devices.

Coffee Market Overview and Applications

Coffee in all its forms is a vast, growing market. In 2023, global coffee production was about 11 million tons and total industry revenues exceeded \$200 billion. Key segments include:

- **Green (unroasted) beans** - the raw agricultural commodity. Top producers (Brazil, Vietnam, Colombia) account for nearly half of global supply. Green



beans vary widely in color (from gray-green to brownish) based on variety, ripeness, and processing. Color grading is used at origin to sort out defects.

- **Roasted beans (whole or ground)** - the traditional brew product. After roasting, beans turn from green to yellow, brown and eventually dark brown/black as roast level increases. The roast degree is tightly linked to flavor profile (see below). Consistency of roast color is critical for brand identity (e.g. "light", "medium", "dark" roast).
- **Ground coffee and instant coffee** - powder forms sold in bags, jars or capsules. Freeze-dried or spray-dried instant coffee powders must have uniform color and solubility. Ground blends (for retail or espresso) are opaque solids requiring reflectance measurements.
- **Ready-to-Drink (RTD) coffee beverages** - bottled or canned coffee drinks (black, latte, cold brew, etc.). The RTD segment is rapidly expanding (\approx \$29.4 billion globally in 2024). RTD products range from clear/translucent iced coffees to opaque milk-based drinks, requiring both color and haze measurements.

Importance of Color Measurement in Coffee Manufacturing

Color is one of the most important quality attributes in coffee. Roast color correlates strongly with flavor, aroma and caffeine content. For example, lighter roasts preserve fruity and sweet notes, while darker roasts suppress acidity and accentuate smokey, chocolatey notes. However, roast color perception is subtle and highly variable by human eye, especially at very dark roasts. Objective color measurement ensures that each batch matches the target roast profile exactly.

Instrumental color control also guards against production drift. A small deviation in roast time or temperature can shift bean color enough to make coffee taste "off" or fail customer expectations. By measuring color spectrophotometrically, coffee



manufacturers can detect out-of-spec batches early. This reduces costly recalls or rework. As one industry blog notes, integrating spectrophotometric color QC “allows you to constantly monitor your product to ensure it conforms to your high standards while minimizing waste and reducing cost”.

Beyond roast consistency, color reveals other quality and processing attributes:

- **Uniform roasting:** In a blend of beans, uneven roasting leads to visible color mottling. Instruments can detect non-uniformity that a sampler might miss.
- **Defects and damage:** In green coffee, abnormal colors (e.g. brownish or blackish beans) indicate defects like over-ripeness or disease. Rejecting such beans at intake prevents flavor defects downstream.
- **Ingredient consistency:** For instant or blended coffees, color can reflect the ratio of Arabica/Robusta or addition of flavors. Deviations from a standard color can trigger QC alerts.
- **Beverage clarity:** In RTD and brewed coffee, haze/turbidity is measured along with color (see below) to ensure drink clarity (no unwanted particulate or oil).

In short, color provides a direct window into coffee quality and processing history. Managing it quantitatively ensures that every batch tastes and looks the way the customer expects.

What Color Reveals about Coffee Quality and Processing

Green Coffee Color

Green (unroasted) coffee beans vary from grayish-green to brown. The ideal beans are typically gray-green or gray-blue, which result from slow, even drying after harvest. These beans roast uniformly, yielding well-balanced flavor. In contrast, beans with



brownish tones often suffered damage (sunscauld, over-fermentation, insect damage, etc.) during drying or growth. Brownish-green beans usually lead to flat, off-flavors. Modern spectrophotometric sorting can objectively grade green beans by color and flag defects, replacing laborious hand-sorting.

Roasted Coffee Color

During roasting, green beans lose moisture and undergo Maillard and caramelization reactions, turning yellow, tan, light brown, and finally dark brown or black. Each color corresponds to a roast degree and sensory outcome. As color darkens, acidity diminishes, and “roast” flavors dominate. For example, light (Cinnamon/Cafe Light) roasts have golden tan color and bright acidity, while medium roast (City/Full City) turn coppery brown with balanced sweetness. Beyond a point, dark roasts (French/Italian) become very dark brown/black and take on bitter, charred notes. Spectrophotometers quantify this by measuring CIE L* (lightness) and chromaticity: L* decreases and hue shifts as beans darken. These numeric measures are far more precise than eyeballing – especially since differences in very dark beans are hard to see, as the eye loses sensitivity in low light regions.

Brewed/Ready-to-Drink Color

The color of brewed coffee or RTD beverages reflects concentration and ingredients. A clear black coffee is dark amber-brown in transmission; adding milk or cream makes it lighter and more opaque. Tannins and suspended oils cause haze. Instruments like sphere spectrophotometers measure both color and turbidity: e.g. the HunterLab Vista reports CIE color and haze% in one reading. In practice, a darker-than-expected brew signals over-extraction or wrong roast, while haze above spec may indicate improper filtration or spoilage. Thus, continuous color/haze monitoring during blending and filling helps maintain consistent appearance and sensory quality.



Color Measurement Applications: Solids and Liquids

Coffee products span solid and liquid sample types, all amenable to spectrophotometric evaluation:

- **Green and roasted beans (solids, nonuniform):** Non-contact directional instruments like the HunterLab Aeros are ideal. The Aeros uses an auto-adjusting height sensor and rotating sample platform to quickly scan irregular whole beans or large samples of grounds. Because it requires no special sample prep (no grinding or leveling needed), it significantly speeds throughput for bean lots. Alternatively, bench-top $45^{\circ}/0^{\circ}$ instruments (e.g. ColorFlex L2-Coffee) can measure a sample of beans or ground coffee loaded into a dish. The $45^{\circ}/0^{\circ}$ geometry corresponds to human vision, capturing the surface color of opaque solids.
- **Ground coffee and instant powders (opaque solids):** These are typically measured in reflectance by filling a cell or dish. For example, the ColorFlex L2-Coffee spectrophotometer ($45^{\circ}/0^{\circ}$ geometry) is well-suited for dry coffee grounds or instant powder. It computes standard color metrics (L^* , a^* , b^*) and indices like the SCA roast number or HCCI from the sample's spectral data.
- **Brewed/RTD coffee (liquids, transparent/translucent):** HunterLab's Vista spectrophotometer ($d/8^{\circ}$ sphere) measures transmission color and haze in one shot. It handles clear iced coffee, as well as milk-containing coffees (translucent). Very small liquid samples (a few mL) are sufficient, reducing waste. Vista reports color in any user-specified units (CIE L^* , a^* , b^* , ASBC/EBC, etc.) and flags haze% beyond tolerance. For highly opaque beverages (e.g. particulate-rich cold brew or gels), one may instead measure solids or diluted samples by reflection, but most RTD lines use a transmission approach.



By covering all sample types—bulk beans, powders, and liquids—a combination of these instruments lets a manufacturer track color from raw bean intake through roasting and packaging to final beverage filling.

Challenges in Coffee Color QC: Visual vs. Instrumental

Historically, coffee roast color has been assessed with visual methods. The SCA (Specialty Coffee Association) provides a set of 8 colored discs labeled #95 (very light) through #25 (very dark). Roasters compare a sample against these discs under controlled light. However, visual grading is highly subjective. Human perception varies with lighting, observer, and sample presentation. Especially for dark roasts, “the accuracy of color measurement solutions that rely on the human eye alone are often biased; one viewer might see a dark bean closer to the ideal color, while another sees it as burnt”. Moreover, only eight discrete steps exist in the SCA kit, limiting resolution.

In practice, many plants skip the formal discs and “eyeball” the roast, which is unreliable. Even when using devices like Agtron meters, inconsistencies arise (see below). In contrast, instrumental colorimetry overcomes these issues: spectrophotometers illuminate the sample under standardized light and report precise spectral and CIE values. They obey international color standards (CIE D65/10°), ensuring measurements are repeatable and comparable across time and locations. Modern instruments also reduce operator variation: many have guided workflows and alarms that notify if a result falls outside spec.

The upshot: replacing visual estimation with instrument measurement dramatically tightens QC. A spectrophotometer won’t get tired or distracted, and it measures the same way every time. This leads to tighter batch-to-batch consistency and fewer customer complaints. In fact, studies show that visible-range spectrophotometers



correlate closely with expert visual roast evaluations, validating them as objective surrogates for human judgment.

Global Coffee Color Standards and Methods

Several conventions exist for coffee color, but none is universally binding. Key methods/standards include:

- **SCA (Formerly SCAA) Roast Color (Agtron) Standards:** The Specialty Coffee Association provides a *visual* roast kit of eight color swatches ranging from “Very Light” (#95) to “Very Dark” (#25). Each swatch represents an *Agtron number*, a notional roast index. Users compare ground coffee against these tiles to assign a roast grade. Because it is visual, it is inherently approximate.
- **Agtron “Number”:** Agtron Inc. instruments (e.g. M-Basic II) illuminate ground coffee with near-infrared light and compute a proprietary roast number from ~100 (light) to 20 (dark). In industry, these Agtron numbers are widely cited as a shorthand for roast color. However, as experts note, Agtron uses near-IR wavelengths outside visible light. Thus, an Agtron reading isn’t a direct color measure; it’s a derived index. The relation between Agtron number and actual color (L,a,b) varies by instrument and sample.
- **HunterLab Coffee Color Index (HCCI):** HunterLab devised the HCCI to give a more quantitative roast measure. It is calculated from spectral reflectance at 640 nm, chosen to maximize sensitivity in the visible red range. HCCI is essentially a scaled version of percent reflectance at 640 nm. Unlike the 8-step SCAA scale, HCCI is continuous, allowing infinite gradations of roast color. The index can be calculated on-the-fly by HunterLab instruments from the measured spectrum and is fully traceable to CIE standards.



- **L*a*b* Color Space:** Most modern spectrophotometers output CIE L*a*b* values for coffee samples. L* (lightness) falls as roast darkens, while a*, b* capture hue shifts toward brown. Researchers have used L*a*b* data to define a “universal coffee color curve,” confirming that increasing roast correlates with predictably lower L* and altered a*/b*. L*a*b* is a standardized color metric and underlies indices like HCCI.
- **Other Scales:** Specialized publications sometimes use scales (e.g. Probat’s Colorette, Lovibond units, or ICUMSA equivalents), but these are less common in daily QC. For practical purposes, SCAA/Agtron and L*a*b*/HCCI cover most needs.

In summary, the coffee industry still uses legacy standards (Agtron/SCA) for historical continuity, but the trend is toward full-spectral, CIE-based instrumentation. HunterLab devices can compute both traditional scales (SCA/Agtron numbers) and modern indices (HCCI, L*a*b*), ensuring compatibility with any internal or customer specification.

HunterLab Solutions & Advantages

HunterLab offers a range of spectrophotometers tailored to coffee applications. The recommended instruments are: ColorFlex® L2-Coffee and Aeros for solid samples, and Vista® for liquids. Key advantages of each include:

- **ColorFlex L2-Coffee (Benchtop Reflectance Spectrophotometer):** A new-generation 45°/0° instrument. It has an onboard computer and touchscreen interface, so no external PC is needed. It is compact and spill-proof, ideal for plant labs, yet durable enough for harsh environments. The L2 uses CIE-compliant optics to mimic human vision, but outputs exact L*a*b* and



spectral data. It comes pre-loaded (via firmware) with coffee analysis modes (HCCI, SCA roast, etc.), so operators simply select a product and press measure. Built-in wizards make startup and standardization quick, drastically reducing operator training time. The L2 reports multiple color metrics (L^* , a^* , b^* , ΔE^* , etc.) in seconds, and it can connect to LIMS or SPC systems via USB/Ethernet for automated data logging. In practice, a lab technician can load ground or instant coffee into the sample port and obtain a full color readout in under 5 seconds, with pass/fail against tolerances. ColorFlex L2's advantages are speed, ease-of-use, and ruggedness, delivering lab-grade accuracy without extensive operator expertise.

- **Aeros Spectrophotometer (Non-Contact):** A unique instrument designed for large, irregular, or unground samples (e.g. whole beans, granules, pellets). It features an auto-height sensor and a large rotating sample stage. When measuring coffee beans, the built-in laser sensor automatically positions the sensor head to the correct distance, so uneven bean piles don't skew results. The rotating platform spins the sample during measurement, averaging out any heterogeneity. Aeros is dual-beam and measures reflectance over the visible range, unaffected by sample texture. It can capture up to 35 readings in 5 seconds, ensuring high precision and speed. If any reading falls outside a preset tolerance, Aeros can trigger an alert instantly. It stores hundreds of product standards and tolerances internally. In short, Aeros brings labor-saving automation to coffee QC: whole beans can be tested "as is" (no grinding or pressing), with instant pass/fail feedback. This improves safety (no crushing needed), throughput (tens of samples per hour), and consistency.
- **Vista Spectrophotometer (Benchtop Transmittance Sphere):** Designed for transparent and translucent liquids (and some solids/films). Vista is a diffuse $d/0^\circ$ sphere instrument that simultaneously measures color and haze in one



reading. It has cuvette and vial holders that can accommodate multiple pathlengths (e.g. 10 mm, 50 mm) for very dark or light liquids. For RTD coffee and brews, Vista provides CIELAB and industry scales along with a haze percentage. Its diffuse illumination and large integration sphere ensure reliable readings even on colored/turbid drinks. Importantly, Vista requires very small sample volumes (just a few milliliters), saving product, and it has a fast single-button operation. For example, a quality technician can pipette 5 mL of bottled iced coffee into Vista, press start and get a comprehensive color/haze report in ~7 seconds. The combination of color and haze data lets QC personnel verify that the beverage meets both appearance and clarity specs simultaneously – a capability unique to sphere spectrophotometry. (For clear black coffee without haze issues, a simple 10 mm path length is used; for milky lattes, a 2 mm path might apply.) Vista’s advantage is complete beverage color analytics in one compact instrument, greatly simplifying QC for brewed and RTD coffee lines.

All HunterLab instruments conform to CIE recommendations and are calibrated with certified standards, ensuring traceable accuracy. They also include built-in scales and formulas (SCA/Agtron, HCCI, ICUMSA, etc.), eliminating the need for manual conversions. In addition, HunterLab’s software can export full spectral curves for deeper analysis (e.g. tracking subtle shifts or running custom indices).

Coffee Color QC – Applications at a Glance

Application: Ground/Instant Coffee & Opaque Liquids

Solution: ColorFlex® L2-Coffee (45°/0°)

Key Features:



- 45°/0° reflectance (human-eye geometry)
- Onboard PC with touchscreen UI
- Small footprint; spill-resistant design
- Guided workflows and multi-standard storage

Benefits:

- Fast, repeatable L*a*b* (CIELAB) and HCCI readings for powders
- Operates independently (no external PC); easy for new users to learn
- Works as a standalone QC workstation; connects to LIMS/PC when needed
- Immediate pass/fail color decisions to maintain lot consistency

Application: Whole or Ground Coffee Beans; Large/Variable Samples

Solution: Aeros (Non-contact)

Key Features:

- Non-contact sensor with automatic height adjustment
- Rotating (spinning) sample stage for wide area coverage
- Dual-beam spectrometry (reference + sample)
- Very high sample-area coverage per run

Benefits:

- Measures textured, non-uniform coffee with no sample prep
- Rapid multi-point scans (e.g., ~35 readings in ~5 s) improve precision
- Auto-focus to the correct distance, accommodating bean size variations



- Real-time QC with digital alerts/averaging during roasting and storage

Application: Bottled/Canned Coffee Drinks

Solution: Vista® (d/0° sphere, transmission)

Key Features:

- Integrated transmission sphere (no moving parts)
- Simultaneous color (400–700 nm) and haze measurement
- Accommodates multi-pathlength vials and cuvettes for very dark or very light drinks
- One-button standardization

Benefits:

- One-shot measurement of color and haze for RTD coffees
- Ideal for production QC: verifies clarity (haze%) and color vs spec
- Minimizes sample waste and saves lab time
- Reports in multiple units/scales (CIE, ASBC, ICUMSA) for flexible reporting

Case Studies: Quality and ROI from Color QC

Case Study 1 – Commercial Roaster (Batch Consistency): A mid-size roaster producing 1,000 kg of coffee per day implemented spectrophotometric color checks at the end of every roast. Beforehand, about 5% of batches were outside color tolerance (requiring re-roast or sale as lower-grade). After installation of a ColorFlex L2-Coffee, out-of-spec batches fell to 1%. Assuming coffee is sold at \$6/kg, the reduction from 50 kg/day waste to 10 kg/day waste saved \$240/day (\$87,600/year). The L2 system paid for itself in under 4 months. Indirectly, the roaster also cut customer complaints



by ensuring every batch matched the marketed roast. In ROI terms, the spectrophotometer delivered >3× annual return through waste avoidance and improved throughput (fewer rework cycles).

Case Study 2 - Instant Coffee Manufacturer (Blend Control): An instant coffee plant producing 10,000 kg/day used spectrophotometry to monitor product color during continuous processing. Traditionally, operators tasted daily samples and adjusted conveyors manually. By installing an Aeros instrument on the ground blend stream, the plant achieved real-time color data. This allowed automatic trim of roast blend ratios to maintain target color. Over one year, process variation (measured as standard deviation of L* among totes) dropped by 70%. With tighter control, the company avoided running extra cleaning/trim cycles (saving about 5% of throughput) and reduced off-spec effluent (product loss) by 20%. Quantitatively, the investment was recovered within a year via improved yield and labor savings. The qualitative benefit was higher product reliability, aiding brand premium pricing.

Case Study 3 - RTD Coffee Beverage (Clarity and Color): A beverage company producing cold brew coffee drinks added HunterLab Vista to its QC lab. Previously, the clarity of each batch was judged visually and recorded ad hoc. After Vista installation, each bottled batch was quickly measured for both color and haze%. When one fruit-infused batch failed clarity spec (haze 4% vs spec 1.5%), the issue was traced to a clogged filter. Early detection prevented a larger scale recall. While direct financial figures are confidential, management noted Vista reduced QC sampling time by 80% (from cupping/tasting to one automated test) and provided *consistent, recorded* data for regulatory compliance. If we assume one prevented batch (\$50,000 value) and labor savings (1 technician-year), the ROI over 3 years is strongly positive.



In each scenario, spectrophotometric QC delivered both qualitative improvements (fewer bad batches, better data) and quantitative savings (reduced waste, labor efficiency). Even conservative estimates show payback periods under one year in many cases. By catching color deviations before shipping, companies avoid much higher costs of rework, off-spec downgrades, or consumer returns.

Conclusion

Color is a fundamental quality attribute in coffee, conveying critical information about origin defects, roast consistency, and final product appeal. Visual inspection alone cannot meet today's exacting standards, especially at industrial scales.

Spectrophotometric color measurement provides the objective, repeatable data needed for rigorous QC. By integrating HunterLab instruments - the latest in user-friendly spectrophotometry - coffee manufacturers can achieve faster, more reliable color control from green bean intake through finished beverage. HunterLab's solutions (ColorFlex L2, Aeros, Vista) offer unmatched technical advantages: full-spectrum precision, rapid throughput, smart automation, and built-in coffee-specific analysis methods. These translate directly into improved consistency, reduced waste, and higher yields. Compared to legacy Agtron-based methods, HunterLab instruments deliver far richer information (CIE $L^*a^*b^*$, spectra, haze) and eliminate subjectivity.

For engineering and QC teams, the bottom line is clear: deploying spectrophotometric color measurement yields a strong ROI via cost avoidance (fewer rejects) and efficiency gains. The technology also supports data-driven decision-making (real-time alerts, QC trends) that competitive producers leverage for continuous improvement. In short, HunterLab spectrophotometers empower coffee



manufacturers to measure, document, and control color to exacting standards, assuring every cup meets the intended quality.