



Enhancing Tea Manufacturing through Spectrophotometric Color Quality Control

Introduction

Tea is one of the world's most consumed beverages, and its visual appearance – especially color and clarity – is critical for consumer acceptance and consistent quality. In industrial tea production, ensuring each batch meets color specifications is a key part of quality control. Spectrophotometric color measurement offers objective, reproducible data on tea color and clarity that go far beyond subjective visual assessment. By replacing human-eyed tests with calibrated instruments, manufacturers can detect subtle variations in tea liquor, leaves, or concentrates, correlate color with processing parameters, and enforce color standards consistently. This paper reviews tea types and the role of color, describes how spectrophotometers are applied in tea manufacturing, compares suitable instruments, and highlights best practices and standards for tea color quality control.

Common Tea Types

All true teas (black, green, oolong, white, pu-erh) are derived from *Camellia sinensis* leaves but differ in processing and oxidation. Green tea is unoxidized, preserving chlorophyll and yielding a bright green to yellow liquor. Black tea is fully oxidized, producing a dark amber-brown infusion. Oolong teas are semi-oxidized, with a color range between green and black teas. White tea is minimally processed (often just withered and dried) and is very light-colored. Pu-erh and other post-fermented teas develop deep brown hues over time. In contrast, herbal “teas” or infusions (e.g. hibiscus, rooibos) are not true teas and can have vivid red, orange or green colors



depending on the botanical and extraction. Each tea type has characteristic color ranges in its dry leaf and brewed form, so understanding these helps set meaningful quality targets.

Importance of Color Measurement in Tea Products

Color is a primary sensory attribute of tea: consumers expect consistency in their favorite tea brand's color, and significant deviations can signal a problem. Consistent tea color also reflects consistency in raw materials (leaf quality, cultivar, season) and process (extraction strength, oxidation, concentration). Objective color measurement ensures that every batch meets brand specifications. In beverage industries, spectrophotometers offer a simple yet effective tool to maintain color consistency and quality.

By quantifying tea color numerically (e.g. CIE L^* , a^* , b^* values or percent transmittance), manufacturers can automate quality checks and detect color drift due to ingredient changes or equipment variation. For example, a spectrophotometer can alert if a green tea infusion is excessively brown (over-oxidized) or if a bottled iced tea is too pale (under-brewed). Stable color data helps optimize processes (adjust brewing time, blending ratios) and ensures that finished tea products (dry blends or liquid drinks) match established standards.

What Color Reveals About Tea

Tea color is directly linked to its chemical makeup and processing. In green teas, chlorophyll is the dominant pigment: fresh, unoxidized leaves retain chlorophyll, which gives brewed green tea its green hue. As leaves are oxidized (or over-steamed), chlorophyll degrades into pheophytins and pheophorbides, which are brown pigments. Black tea color comes from these brown chlorophyll breakdown products along with polyphenols like theaflavins (orange hues) and Thearubigins (red-brown



hues). Thus, a bright yellow-green infusion suggests high chlorophyll (fresh green leaf), whereas a reddish-brown color indicates extensive oxidation (as in black tea). Color can also indicate concentration or dilution: stronger brews are darker (lower L^* value), and lighter values mean weaker tea. Additionally, cloudiness or haze in the liquor (discussed below) reveals suspended solids or incomplete filtration. In summary, tea color (and related metrics like hue and lightness) serves as a proxy for leaf maturity, oxidation level, brewing strength, and clarity.

Applications of Color Measurement in Tea Manufacturing

Instrumental color measurement can be applied at multiple stages of tea production and packaging:

- **Raw material inspection:** Assess fresh or dried tea leaves for expected color (e.g. matcha powder should be vivid green, CIE a^* strongly negative), detecting off-color or improper processing early.
- **Brew/Extraction control:** Monitor the color of brew liquor or concentrate during boiling/steeping. For example, spectrophotometers can measure transmittance or absorbance to control extraction endpoints, ensuring consistent brew strength and preventing over- or under-extraction.
- **Filtration/Clarity checks:** Measure haze or turbidity in hot tea liquor after filtration. High turbidity or haze (low %T) may indicate poor clarification, which affects flavor and shelf stability. Instrumental haze measurement provides a precise metric for clarity instead of subjective eyeballing.
- **Final product QC:** In ready-to-drink teas (bottled or canned), color measurement ensures each package matches the standard color specification. This is crucial for consumer trust (e.g. iced tea should always have the expected amber hue, with minimal batch-to-batch variation).



- **Blending and formulation:** When blending different teas or ingredients (e.g. fruit/herb additives, milk in milk tea), spectrophotometers guide the mix ratios needed to hit target color values. This accelerates development of new formulations by quantifying color outcomes.

By integrating spectrophotometry into the QA workflow, tea manufacturers can streamline routine checks (faster than titrations or manual testing) and catch deviations that might otherwise be missed. Spectrophotometers eliminate subjective error in visual checks and let QC personnel test many samples quickly with one instrument. For example, rather than relying on a color chart or single-wavelength absorbance, a full-spectrum reading yields complete L^* , a^* , b^* and haze data in seconds. Such data help quantify quality and drive consistent production.

Challenges in Applying Color Measurement to Tea QC (Especially Visual Methods)

Tea presents some challenges for color quality control, particularly when using human assessment or simplified instruments. First, **visual inspection is highly subjective**. Lighting conditions, sample volume, container shape, and human factors (fatigue, color vision deficiencies) can all skew perception. Two operators may judge the same tea differently, especially when color differences are subtle. Visual checks also become impractical with large sample batches. Second, many traditional QC specs rely on a single parameter (e.g. percent transmittance at 660 nm). Such one-dimensional specs can miss important issues. For instance, in a case study the customer's pass/fail was only based on %T at 660 nm, and both batches passed that test, but the second batch was visibly darker and more yellow due to under-dilution. Only the full-color (L^* , a^* , b^*) and haze measurements revealed the problem. Third, sample heterogeneity is an issue: tea leaves or powders have uneven color and texture, and liquor may contain suspended particles or foam. Proper sample preparation (e.g. grinding, filtering,



agitation) is needed for repeatability. Lastly, different tea matrices may require different measurement approaches (e.g. translucent brewed tea vs. opaque matcha slurry), so using the wrong instrument geometry can lead to unreliable data. These challenges underscore the need for **standardized instrumental methods** rather than eyeballing or single-wavelength checks.

Best Methods and Recommendations for Instrumental Spectrophotometric Color Measurement

For accurate tea color QC, laboratory-grade spectrophotometers with appropriate measurement geometry are recommended. Key best practices include:

- **Use full-spectrum color instruments:** Employ a visible-range spectrophotometer (400–700 nm) that outputs CIE color values (L^* , a^* , b^*). This provides a complete color characterization instead of just absorbance at one wavelength.
- **Select the right geometry:** For liquid teas (transparent/translucent), use a transmission sphere spectrophotometer (like Vista) to capture both transmittance and haze. For solid/opaque samples (tea leaves, powders, concentrates), use a $45^\circ/0^\circ$ reflectance instrument (like ColorFlex L2).
- **Calibrate regularly:** Calibrate with NIST-traceable white and black standards and verify performance with reference tiles or solutions. For haze measurements, use certified haze standards (1%, 5%, etc.) to ensure compliance with ASTM D1003.
- **Control sample conditions:** Maintain consistent sample presentation (e.g. pathlength for liquids, sample thickness for solids). For liquids, use clean, optically clear cuvettes or vials; for powders, use a sample cup or dish that fills the optical aperture uniformly. Temperature and bubbles should be controlled since viscosity and scattering can affect readings.



- **Account for haze/turbidity:** Measure haze% for transparent teas (see next section), as clarity is as important as color. Ensure the instrument's integrating sphere and detectors meet the ASTM D1003 haze method (Procedure B).
- **Document and standardize:** Define and document acceptable L^* , a^* , b^* ranges or tolerances for each product. Use the spectrophotometer to generate reference "master" readings. Automated color-difference criteria (ΔE) can trigger alerts.
- **Training and SOPs:** Provide operators with standard operating procedures and training on instrument operation to avoid errors like wrong geometry setting or forgetting to subtract the baseline.

By following these recommendations, tea makers can obtain objective, repeatable color data that directly tie back to product quality. Spectrophotometers can analyze the color of tea leaves by detecting changes in transmitted and reflected light...faster and more precisely than human inspection. This data-driven approach removes guesswork from tea QC.

Measuring Haze and NTU in Transparent/Translucent Liquid Tea Products

In clear tea beverages (brewed teas, iced tea, kombucha, filtered liquid extracts), turbidity or haze is an important quality attribute. Haze is defined as the percentage of light scattering in a liquid sample according to ASTM D1003. A high haze% means the liquid is cloudy; low haze% means very clear. Haze can result from tiny, suspended particles (tea solids, precipitated polyphenols, proteins) and often correlates with mouthfeel issues or instability. It is measured using a spectrophotometer with an integrating sphere (ASTM D1003 Procedure B), which detects both direct transmittance and scattered light. HunterLab's Vista spectrophotometer is designed to



meet this standard: it is a double-beam, sphere-based transmission instrument that fully complies with ASTM Procedure B for haze.

Nephelometric Turbidity Units (NTU) is another measure used in water and beverage industries (measured at 90° scatter). While a spectrophotometer primarily reports %Haze, a turbidity meter (nephelometer) can provide NTU readings. Some color spectrophotometers can be configured to report NTU by measuring scattered light at 90°. For tea QC, either metric can alert to excessive turbidity. In practice, one would use the Vista to measure %Transmission and haze%; in parallel, a portable turbidity meter could be used if needed for NTU values. The key point is that transparent tea products must be evaluated for both color (hue, strength) and clarity. A sample with the correct hue but high haze could indicate a filtration or settling problem that must be corrected.

Instrumentation Comparison

HunterLab Vista:

The Vista is a benchtop double-beam spectrophotometer with an integrating sphere, optimized for transparent and translucent samples. It uses a broad-spectrum LED source and a 400–700 nm detector to simultaneously measure transmission color and haze. Vista's design follows ASTM D1003 (Procedure B), so it inherently reports %T, %Haze, and L^* , a^* , b^* in one scan. This makes it ideal for monitoring brewed tea color, concentration, and clarity in-process or in finished beverages. The Vista is compact ($\approx 19 \times 9 \times 7$ inches) and features automated calibration routines and a spill-resistant sample compartment. Its embedded software (EasyMatch Essentials) guides the user through measurement and stores color data automatically. Because Vista answers the question "what color is it?" and "how clear is it?", it is best suited to clear tea products (e.g. bottled green tea, black tea, kombucha). Its ability to provide both



spectrophotometric color and haze in one reading significantly enhances defect detection and process control.

HunterLab ColorFlex L2:

The ColorFlex L2 is a 45°/0° reflectance instrument powered by a pulsed xenon light source. It is designed to measure powders, granules, solids, and even creamy or opaque liquids. The L2 features a sealed, spill-proof housing and a modern touchscreen interface, so no external computer is needed. It reports full spectral reflectance and computes L^* , a^* , b^* values according to CIE standards. ColorFlex L2 can measure everything from opaque solids and powders to translucent liquids with excellent repeatability. In tea manufacturing, it is ideal for non-transparent samples: for example, it can assess the color of matcha tea powder or crushed tea leaves, or even an opaque ready-to-drink “milk tea” where Vista’s transmission would fail. The L2’s ergonomics (small footprint, quick startup) and durability make it suitable for QC labs. Its robust calibration against white and black standards ensures data traceability. In short, Vista excels for liquid tea products (brewed tea, cold brew, clear concentrates), while ColorFlex L2 is ideal for dry tea, tea granules, pastes, and any opaque formulation.

Case Studies

- **Case Study 1 – Tea Dilution Monitoring (Vista):** A green tea concentrate was produced in three stages, each requiring a %T test at 650nm. In one trial, a batch passed the %T specification at Stage 1 but tasted too strong. Using a Vista spectrophotometer, technicians measured additional parameters and found that, although %T was acceptable, the second batch had a much lower L^* (darker) and higher b^* (more yellow) compared to a control (first) batch.



Importantly, the 2nd batch had a low haze (7%) vs. 30% in the first batch, confirming its clarity. The combined data (darker color + high sugar and pH) indicated the tea was under-diluted. Indeed, it was later found that 2,000 gallons of water were inadvertently omitted. After correcting the dilution (adding water), the product met both sensory and chemical specs. *This case shows how measuring L^* , a^* , b^* and haze with Vista (not just %T at one wavelength) pinpointed a dilution error, saving a batch that would have otherwise been rejected.*

- **Case Study 2 - Matcha Powder Color (ColorFlex L2):** A producer of Japanese matcha tea needed to ensure each lot met a deep-green color standard. Using ColorFlex L2, QC personnel measured the CIE L^* , a^* , b^* values of samples from different leaf grades and processing batches. They found one tea field yield had a higher L^* (lighter) and a smaller negative a^* (less green) than their standard. Further chemical testing confirmed lower chlorophyll content. By blending this lot with younger-leaf matcha, they adjusted the color back into specification. Routine L2 measurements thereafter ensured each matcha shipment fell within the target color range, reducing off-color complaints.
- **Case Study 3 - Bottled Black Tea Clarity (Vista):** A bottler of sweetened iced black tea saw occasional batches with a hazy appearance. Laboratory testing with the HunterLab Vista showed that haze% was spiking above acceptable limits, even though the brew color (L^* , a^* , b^*) remained within range. Investigation revealed a filter membrane nearing end-of-life. After replacing the filter, haze% returned to <5% and the tea was clear. Regular Vista haze monitoring was then instituted as a preventative QC step. This streamlined detection of turbidity issues without relying on off-line titration or eyeball checks.



Competitive Comparison: HunterLab vs. UV-Vis Spectrophotometers

Color spectrophotometers like HunterLab's are often compared to analytical UV-Vis instruments. The key differences are purpose and data. A UV-Vis spectrophotometer covers a broad range (typically ~200-1100 nm and higher) and measures absorbance at fine spectral intervals (often ≤ 2 nm) for quantitative chemical analysis. In contrast, a HunterLab colorimeter focuses on the visible range (400-700 nm) and answers the question "what color is it?". HunterLab devices sample at 5-10 nm intervals and compute colorimetric values (L^* , a^* , b^*) that correlate with human perception. In practice, a UV-Vis can be used to compute color (via software), but it requires special attachments (sphere, reflectance cells) and optional color software. HunterLab instruments have color-formula software built in, calibrated to standard illuminants and observers, so they give direct color readings out-of-the-box.

In operational terms:

- **Spectral range:** Both can measure 400-700 nm, but UV-Vis also covers UV. If only visible color is needed, HunterLab's built-in LED/detector optimized for color yields faster readings and simpler operation.
- **Geometry and sample handling:** HunterLab's sphere optics and 45/0 fixtures are purpose-built for color, whereas UV-Vis systems may require external probes or integrating spheres for solids and haze, for example attaching an integrating sphere accessory for hazy liquids. HunterLab units include these optics as standard (Vista has a built-in sphere; ColorFlex has a fixed 45° geometry).
- **Ease of use:** Vista and ColorFlex L2 spectrophotometers have touchscreen interfaces and are designed for QC lab use, with minimal training. UV-Vis



instruments are generally lab bench units requiring more user expertise (e.g. setting scan parameters, curating baseline).

In summary, HunterLab color spectrophotometers quantify the human perception of an item's color while a UV-Vis focuses on correlation to spectral data, a purely physical property. Thus, for tea QC where perceptual color consistency is the goal, HunterLab instruments offer a more direct and efficient solution. UV-Vis systems are excellent for assays and research, but HunterLab instruments are "best-in-class" for practical color quality control and come pre-packaged with color metric standards.

Regulatory Standards and HunterLab Compliance

Tea production must comply with industry standards for instrumentation and data.

Relevant standards include:

- **ASTM D1003:** This is the standard test method for haze in transparent plastics and liquids. HunterLab's Vista is fully compliant with ASTM D1003 Procedure B (which requires a dual-beam, spherical detector instrument). Vista units are factory-certified using ASTM haze reference standards. Thus, tea manufacturers can trust Vista's haze% values to meet ASTM specs if needed (e.g. for regulatory or customer contracts).
- **CIE and ISO Color Standards:** HunterLab instruments report CIE color values (L^* , a^* , b^* etc.) calibrated to CIE standard illuminants and observers. They adhere to ISO and ASTM color measurement practices (e.g. ISO 787-24, ASTM E1164) by using traceable white tiles and black glass standards. HunterLab's quality system is ISO 9001:2015 certified, and their lab and instruments are ISO 17025-accredited. All models are CE marked for sale in global markets. These certifications ensure consistent, reliable color data under repeatable conditions.



- **21 CFR Part 11 (for Pharma/QC software):** If color data is part of a regulated drug or supplement process, electronic records must be secure. HunterLab’s Vista and ColorFlex L2 offer an “ER” (Electronic Record) software option that includes audit trails and security features compliant with FDA 21 CFR Part 11. This allows pharmaceutical/food companies to use HunterLab instruments in a fully compliant environment.

In summary, HunterLab’s instruments and software meet or exceed relevant regulatory requirements. Certificates of compliance for ISO 9001/17025 and CE marking are available from the manufacturer. Tea producers can therefore integrate HunterLab colorimeters into ISO-certified quality systems, with traceable calibration standards and optional Part 11 security if needed.

Summary Table: Vista vs. ColorFlex L2 Features

Feature	HunterLab Vista	HunterLab ColorFlex
Measurement	Transmission (integrating	Reflectance 45°/0°
Geometry	sphere, d/0°)	
Light Source	LED (400–700 nm)	Pulsed Xenon (400–700 nm)
Sample Type	Clear or filtered liquids (brewed tea, bottled teas, kombucha)	Opaque liquids and solids (tea powders, concentrates, milk tea)
Haze/Turbidity	Measures %Haze (ASTM D1003) and reports %T	N/A (not used; only reflectance)
Typical Applications	Color and clarity of clear tea beverages	Color of solids/powders and non-transparent samples



Feature	HunterLab Vista	HunterLab ColorFlex
Calibration Standards	NIST-traceable white tile, haze standards (0-30%)	NIST-traceable white tile; ceramic/glass calibration tiles
Software/Interface	Onboard touchscreen, PC optional; EasyMatch Essentials (with 21 CFR 11 ER option)	Onboard touchscreen, PC optional; EasyMatch Essentials (with 21 CFR 11 ER option)
Data Output	%Transmission, %Haze CIE L*, a*, b*, Hunter L, a, b, ΔE Color Difference, other color scales and color indices	CIE L*, a*, b*, Hunter L, a, b, ΔE Color Difference, other color scales and color indices
Key Advantages	Captures haze & color in one measurement; ideal for liquid tea quality control	Measures any solid or opaque material; sealed case (spill-proof); fast results

Table: Key features and application benefits of Vista vs. ColorFlex L2 for tea color measurement.

Conclusion

Effective color quality control in tea manufacturing relies on objective, instrument-based measurement. Using spectrophotometers (rather than human eyeballing) enables tea producers to quantify color and clarity consistently. Transparent tea products (brews, bottled teas) are best measured with a transmission sphere spectrophotometer like HunterLab’s Vista, which provides color plus haze data according to ASTM standards. Opaque or solid tea samples (powders, concentrates, milky drinks) require a reflectance instrument like HunterLab’s ColorFlex L2. Both instruments are calibrated to scientific color standards, minimizing drift and ensuring repeatability.



HunterLab solutions stand out because they are specifically engineered for color QC. They answer “what color is it?” with traceable metrics, unlike general UV-Vis spectrophotometers which are geared toward chemical analysis. Case studies show how full-spectrum color analysis can detect process deviations that simpler tests miss. By following best practices (proper geometry, calibration, and analysis of color and haze data), tea technologists can optimize tea processes (brew strength, blending, filtration) and reduce waste. In short, integrating HunterLab spectrophotometers into tea production QC yields data-driven insights, consistent product quality, and greater confidence than visual methods alone.