Enhancing Tomato Product Manufacturing with Spectrophotometers for Color Quality Control

Introduction

Color is one of the most important quality attributes in tomato products, directly influencing consumer appeal, perceived freshness, and even product grading. In the tomato processing industry – from tomato paste and ketchup to sauces, juices, and diced tomatoes – consistent color quality control is paramount. Traditional visual assessment of color is subjective and can lead to inconsistencies. This is where spectrophotometers come into play.

By using the science of light to measure color objectively, food processors can achieve tighter quality control, ensure consistency across batches, and meet industry standards more reliably. Spectrophotometric color measurement has been embraced by both industry professionals and regulators (such as the USDA) as the gold standard for tomato product color evaluation.

In this white paper, we delve into how modern spectrophotometers – with a focus on HunterLab's ColorFlex L2 and the HunterLab Tomato Certified Reference Standard– enhance tomato product manufacturing through improved color quality control. We will explore the significance of color in tomato products, what color reveals about product quality (including correlations to lycopene content, maturity, and flavor), applications of color measurement throughout processing, and best practices for implementation. We'll also provide a competitive comparison of available instruments and highlight case studies demonstrating the return on investment (ROI) and quality improvements achievable with instrumental color measurement.

Finally, given HunterLab's long history in tomato color standards (including the development of the renowned "tomato tile" reference standard), we will review the evolution of tomato color standardization and how these instruments are helping maintain best-in-class color quality in tomato products.

Importance of Color Measurement in Tomato Products

Color is often the *first* quality cue for both consumers and quality graders of tomato products. A rich, vibrant red color is associated with ripeness, robust flavor, and high nutritional value, whereas a dull or brownish tint may signal inferior quality or over-processing. In fact, color is such a strong indicator of quality that in official grading of processed tomato products, 30 out of 100 points are attributed solely to color. USDA grading standards for products like tomato paste, sauce, juice, and ketchup set specific color requirements – products must fall within exact color ranges for Grade "A" (Fancy) or other grade classifications. Where a product lands on the color scale can significantly impact its market value and consumer acceptance.

From a consumer perspective, studies have shown that color heavily influences purchasing decisions and taste expectations. Tomato products are prized for their intense red hue (often described as a bright magenta-red), which consumers equate with freshness and full flavor. A brighter red ketchup or tomato sauce, for example, is generally preferred over a pale one. Thus, maintaining consistent color not only ensures regulatory compliance and grade but also helps meet customer expectations and brand consistency.

For processors, objective color measurement is critical to process control. As tomatoes are processed into various products, color is monitored as a key quality attribute at every stage. Processors use color data to decide blending of tomato lots, optimize processing conditions, and determine if a batch meets the desired specification. Precise color measurement allows them to grade tomato products objectively and make data-driven decisions. This objectivity is crucial in trade of bulk tomato paste or juice concentrate, where buyers and sellers rely on color scores to agree on quality and price. In bulk markets, "you can't sell paste or diced tomatoes unless a color number is put on it" – meaning an objective color score is essentially a requirement for commerce. With a spectrophotometer, producers can provide customers with confidence that each shipment meets the agreed color standards.

In summary, color measurement in tomato products is important because it: (1) Indicates quality and freshness, correlating with chemical constituents like lycopene and influencing flavor perception; (2) Determines grade and market value in accordance with USDA or other standards; (3) Drives consumer appeal and brand consistency; and (4) Enables process control and waste reduction by catching off-spec product early. Ensuring accurate and consistent color through instrumental measurement therefore has strong economic and quality incentives for tomato processors.

What Color Reveals About Tomato Product Quality

Color in tomato products is not just cosmetic – it is a window into the product's intrinsic quality. The development of red color in tomatoes (and their processed derivatives) is primarily due to the pigment *lycopene*, a carotenoid with well-known health benefits. As tomatoes ripen, chlorophyll (green pigment) decreases and carotenoids like lycopene and beta-carotene increase, producing the characteristic red color. Therefore, a deeper red color generally signifies a higher lycopene content and a more mature, fully ripe tomato. Spectrophotometric measurements can quantitatively capture this: for example, the ratio of absorbance or the colorimetric value *a* (redness) relative to *b* (yellowness) – the a/b ratio – is often used as an index of redness. Research has found that the a/b ratio correlates strongly with lycopene levels in tomatoes across ripeness stages. In one study, color readings (especially a, and a/b) produced the best regressions with lycopene content measured by HPLC, and the authors were able to devise equations to estimate lycopene concentration from color values. In practice, modern tomato-dedicated spectrophotometers like the ColorFlex L2 can even output a calculated Lycopene Index based on colorimetric data, giving processors a rapid estimate of lycopene content without resorting to chemical analysis.

- Maturity and ripeness: The color of a tomato product reflects the maturity of the tomatoes used. Fully ripe tomatoes contribute a rich red color, whereas tomatoes harvested early (at the breaker or pink stage) yield a more orange or yellowish product due to lower lycopene and higher beta-carotene and residual chlorophyll. Thus, color can be a proxy for ripeness. A high-quality tomato paste or puree made from well-ripened fruit will have a high a/b ratio (indicating a strong red hue), whereas a lower-quality paste might be lighter or more orange if under-ripe fruit were included. By measuring color, quality control can infer if the raw material mix was optimal or if adjustments are needed (for instance, to exclude green tomatoes). In the case of whole canned or diced tomatoes, color sorting is often used to remove green pieces, and an overall color measurement of the finished product can indicate if proper ripeness selection occurred.
- Lycopene content and nutrition: As noted, red color intensity correlates with lycopene content, which is a valued nutritional component (an antioxidant linked to health benefits). For producers of tomato juice, sauces, or ketchup who may want to market the health aspects of their product, being able to monitor lycopene via color is useful. A more intensely colored product generally signals higher lycopene, which can be a quality selling point.

Spectrophotometers provide a non-destructive means to estimate lycopene quickly, ensuring each batch retains a target nutritional profile.

- Flavor indicators – sugar/acid balance: The sugar and acid content of tomatoes also change with ripening, although these are not directly measured by color. Typically, as tomatoes ripen and redden, sugars (such as fructose and glucose) increase and some acids (like malic acid) decrease, leading to a higher sugar-to-acid ratio (a sweeter taste) in fully ripe tomatoes. While color doesn't measure sugar or acid, it *does* serve as an indirect indicator: a batch of tomatoes that achieved a deep red color likely ripened on the vine longer, accumulating more sugars and a better flavor balance. In processed products, an off-color can hint at flavor issues – for example, tomatoes that were not ripe (yielding a more yellow-orange sauce) might also taste more sour or "green." Moreover, excessive brownness in a tomato product's color might indicate overcooking or thermal degradation (Maillard reactions), which can correspond to a cooked or burnt flavor. Thus, maintaining the ideal color guards not only appearance but also helps ensure the process preserved the desired flavor profile. Quality specialists often monitor color along with Brix (soluble solids) and acidity; any deviation in color triggers a check on these parameters as well.

In summary, color reveals multiple facets of tomato product quality: it is a marker for lycopene content and nutritional value, an indicator of raw material ripeness and thereby flavor potential (sugar/acid balance), and a clue to processing conditions (with color degradation hinting at potential flavor or nutrient losses). By quantifying color with a spectrophotometer, manufacturers gain insight into these quality attributes in real time. For instance, if a tomato juice's color measurement shows lower redness than expected, it could prompt checks on the ripeness of tomatoes used or adjustments to the blend to meet both color and taste standards. Instrumental color data essentially become a quality fingerprint, closely tied to the product's composition and consumer satisfaction metrics.

Applications for Color Measurement Across Tomato Processing and Manufacturing

Color measurement using spectrophotometers has versatile applications at every stage of tomato processing, from raw harvest assessment to final product quality control. Below, we outline how color is monitored and managed in raw materials, in-process products, and finished goods, covering a range of tomato product types:

- Raw Tomatoes (Incoming Quality and Sorting): Before processing even begins, tomato processors benefit from measuring the color of incoming fruit. Fresh tomatoes can be evaluated for their Fresh Tomato Color Index (FTCI), an objective metric that indicates ripeness. Instruments like the ColorFlex L2 Tomato are equipped to measure whole tomato color to grade ripeness: for example, growers or processors can sample tomatoes from a truckload to ensure they meet the desired color maturity (minimizing the proportion of green or unripe fruit). Color data at this stage might be used to sort tomatoes (many facilities use optical sorters to remove green tomatoes) or to decide blending strategies (mixing lots of varying ripeness). Additionally, plant breeders and agricultural specialists use spectrophotometers to evaluate new tomato varieties for color development and lycopene content, which ties into selecting breeds that produce the richest color in processing. In summary, measuring raw tomato color helps ensure that only suitably ripe tomatoes enter production, which sets the foundation for good color in final products.
- In-Process Monitoring (Grinding, Pre-heating, and Concentration): Once tomatoes are processed (e.g., washed, ground into mash, and cooked), color measurement continues to be vital. For tomato paste and puree production, in-process color checks can be done after juice extraction or during concentration. For instance, a sample of tomato juice might be taken from an evaporator and measured for its color values (L, a, b). If the color is too pale, it might indicate

either dilution (low solids) or insufficient maturity, prompting adjustments such as prolonging concentration or blending in some more deeply colored material. Many processors use a spectrophotometer in the lab to test batch samples from various stages: after initial hot break (to ensure enzymes are inactivated without color loss), mid-concentration, and final concentration. Tomato Paste Score (TPS) – a standardized color score – can be computed for in-process samples to predict the grade the paste will achieve. If the TPS is trending low, operators can take corrective action (e.g., concentrate further to deepen color, or adjust temperature to avoid browning). In making ketchup or sauces, color can be measured after mixing ingredients to ensure the tomato base is within spec *before* cooking down and bottling. This kind of in-process QC helps in real-time decision making: saving a batch that might otherwise be out of spec, or optimizing processing parameters (temperature, cook time) to maximize color retention. Some advanced installations even have inline color sensors or take frequent samples to track color continuously.

- Finished Products (Quality Control and Grading): The final step is verifying that the finished tomato product meets color specifications. Spectrophotometers are used to test tomato paste, ketchup, sauces, tomato juice, diced tomatoes, and other products in their final form:
    - *Tomato Paste/Purée:* These are typically measured in a glass sample cup designed for the spectrophotometer. A small amount of paste is placed in the cup and read with a 45°/0° reflectance geometry (often under Illuminant C/2° observer as per standards) The instrument may directly output the Tomato Paste Score (TPS), which correlates with USDA grade. For example, a TPS above a certain threshold might indicate U.S. Grade A (Fancy) color. This objective grading is crucial for bulk paste which is sold to other food manufacturers – contracts often specify a minimum TPS or a/b ratio. By measuring each batch, the processor can certify the

grade, and buyers can verify it upon receipt. If a paste does not meet the target color grade, it might be blended with a higher-color batch or used in a lower-tier product, rather than mislabeled. Thus, color QC prevents grade disputes and ensures the right product for the right application.

- *Ketchup and Tomato Sauce:* These consumer-facing products demand color consistency for brand identity. Ketchup, for instance, is expected to have a rich red appearance without being brown or pale. Manufacturers measure ketchup color in the lab (usually by filling a sample cup or a small petri dish and reading in reflectance). The spectrophotometer can report the Tomato Catsup Score (TCS) which is a standardized metric for ketchup color. Similarly, a Tomato Sauce Score (TSS) exists for formulations like tomato sauce or salsa. These scores are derived from the color coordinates (a, b values) via formulas developed to match visual grading. By checking the score, QC can confirm that each batch of ketchup or sauce will look the same to consumers. If a batch falls outside the acceptable range, it might be reworked (for example, slightly concentrated if too light, or diluted if too dark and thick). Maintaining consistent color batch-to-batch fosters consumer trust – imagine if one bottle of a brand's ketchup was noticeably browner than another. Top brands have tight tolerances and use instruments to enforce them. In fact, some major ketchup manufacturers have implemented spectrophotometers at multiple points in production to get early warnings if color drifts out of spec.
- *Tomato Juice:* Tomato juice is both an end product (canned/bottled juice for consumers) and an intermediate (e.g., tomato juice concentrates for making sauces). Color in tomato juice is measured by placing the juice in a clear cuvette or sample cup and reading either in reflectance (with a white backing behind the cell) or in transmittance if the instrument

supports it. Generally, 45/0 instruments like ColorFlex L2 measure it in reflectance mode by treating the juice as an opaque liquid (when sufficiently thick layer is used). The instrument can output a Tomato Juice Score (TJS) which correlates with visual juice grade. A high-quality tomato juice will have a deep red color (high a, moderate b), whereas an inferior one might appear orange (lower a/b). Processors measure this to control blending of juices from different tomato varieties or lots to achieve a uniform color. In consumer juice, color also relates to flavor perception – a bright red juice suggests robust flavor, whereas a dull color may be perceived as bland. Therefore, QC ensures each production run meets the established color standard (often defined by internal targets or industry norms).

- *Diced and Whole Canned Tomatoes:* These products are more challenging to measure because they consist of pieces of tomatoes (with skin and pulp) in a liquid matrix. However, color evaluation is still crucial. Visually, canned diced tomatoes are graded on the percentage of units that are not red (green or yellow pieces reduce the grade). Instrumentally, one approach is to take a representative sample of the diced tomatoes (drain the liquid or include it proportionally) and blend it into a uniform slurry, then measure that slurry's color. This gives an objective overall color that correlates with the visual appearance. Another approach is to measure the drained liquid (which contains soluble color) and the solids separately. In practice, many packers rely on visual inspection for diced/whole tomatoes due to the heterogeneous nature, but as imaging spectrophotometers advance, it's possible to capture the color of many pieces at once. For example, the HunterLab ColorFlex L2 5-megapixel imaging capability can be used to analyze the color of a whole tray of diced tomatoes, giving both an average color and the distribution (it could theoretically identify the lighter pieces vs darker) – a task traditional single-point instruments cannot do easily. In any case, ensuring that diced tomatoes have a good red color (and not too many pale chunks) is important for customer satisfaction, especially for retail canned products where the tomatoes are visible or described as e.g. "red ripe tomatoes".

- *Other Tomato-Derived Products:* Color measurement also applies to tomato-based soups, pastes with seasoning, or even dried tomato powder. For instance, a powdered tomato soup mix would be checked for color to ensure it was made with properly processed tomato solids. Wherever color consistency is tied to ingredient quality (in spice blends containing tomato powder, or snack foods with tomato seasoning), spectrophotometers can quantify the red-orange hue to maintain batch-to-batch uniformity.

Across all these applications, spectrophotometers serve as critical tools for quality assurance. They allow manufacturers to maintain color traceability from raw material to finished products. Many companies create color specification databases for each product type. Each lot's color data is recorded, and trends are monitored over time. This helps with continuous improvement (for example, if a trend of slightly decreasing redness is observed over a season, the company might work with growers to adjust varietals or ripeness for next year). It also eases regulatory compliance and audits – having instrument-backed color data shows that the company is controlling a key quality attribute diligently.

Lastly, color measurement data is often shared across the supply chain. An industrial bulk buyer of tomato paste will measure the paste upon arrival to confirm it matches the Certificate of Analysis (which includes color scores) from the supplier. Because both supplier and buyer are likely to use similar instruments and perhaps even referencing the same tomato color tile standard for calibration, their measurements will agree closely, reducing conflicts. This harmonization, enabled by standard use of spectrophotometers, greases the wheels of commerce in the tomato industry. In summary, from farm to factory to final product, instrumental color measurement is deeply embedded in the tomato product manufacturing process.

Challenges in Visual Color Evaluation and Color Control

Relying on the human eye alone to judge tomato product color poses numerous challenges. Visual color evaluation is inherently subjective and inconsistent – what one person perceives as an acceptable red, another might judge as too orange or too brown. Several specific challenges make visual assessment problematic:

- Human Subjectivity and Variability: People have varying color perception. Factors such as age (older eyes see colors differently), color vision deficiencies, and even language (describing color) can lead to inconsistent judgments. In a production environment, if color decisions are made by different operators or at different times of day, the outcomes can vary widely. For example, one QC technician might have a bias to call a batch "off-color" while another might pass it as fine. This subjectivity can result in erratic product quality over time or disputes over whether a batch meets specification. By contrast, a calibrated spectrophotometer provides numerical values (Hunter L, a, b or indices like TPS) that are objective and reproducible, eliminating interpersonal variation.
- Lighting Conditions: The appearance of color is highly dependent on the lighting. A tomato sauce might look richly red under daylight but appear dull under fluorescent lighting. Visual inspections need to be done under standardized lighting (often a light booth with D65 or some agreed illuminant), but not all facilities have such controls. In many plants, color might be checked under whatever ambient lighting is present, leading to inconsistent results.

Spectrophotometers solve this by using controlled illumination (standardized light sources built into the instrument) and by computing color values for standard illuminants (like C or D65). This ensures that the color is evaluated under defined conditions every time, something the human eye alone cannot guarantee unless very carefully managed.

- Color Memory and Adaptation: The human eye can adapt to lighting and color contexts, which can fool operators. For instance, after looking at very red products for a while, a person's eyes may become less sensitive to red (chromatic adaptation), potentially causing a slightly less red sample to mistakenly appear acceptable. Or if a person views a green surface and then looks at a tomato product, their eye may momentarily perceive the tomato color differently (a phenomenon of successive contrast). Human observers also have limited memory for color – it's hard to remember exactly what shade a reference standard was once you are looking at a sample. Traditionally, visual methods used physical standards (like colored tiles or liquid standards in containers) side-by-side with the sample for direct comparison, to mitigate memory issues. But even then, differences in gloss or texture can mislead the eye. Spectrophotometers essentially have "perfect memory" – they can store standard readings and compare new readings mathematically to compute color differences (ΔE values), providing a clear pass/fail indication within tolerances.
- Fatigue and Speed: Performing visual comparisons is time-consuming and tiring. If a technician must grade dozens of samples a day by eye, their accuracy can degrade over time as eye fatigue sets in. Slight color differences might be missed late in the shift. In contrast, an instrument can measure a sample in a few seconds and doesn't get tired. This improves throughput – many more samples can be measured objectively in the same time it would take to do a few visual comparisons. Faster feedback from instrument measurements also means

process adjustments can be made more quickly (reducing the amount of off-spec material produced).

- Environmental Influences: Ambient factors like background color, surrounding objects, or container color can influence visual perception. For example, tomato juice in a clear glass might look different if the background of the room is white vs. if it's a colored wall. Reflections and glare (for glossy products like ketchup on a slick surface) can also interfere – our eyes might confuse shine for brightness of color. A 45°/0° geometry spectrophotometer is designed to exclude specular glare and measure only the color of the material, which makes it more reliable. Moreover, the instrument usually has a defined sample presentation (like placing a sample cup against a black shroud), eliminating background distractions. This consistent viewing geometry and background control is hard to achieve with the naked eye unless one uses a standardized viewing setup for every sample.
- Reproducibility and Data Logging: Visually determining that "Batch A is a bit redder than Batch B" is qualitative. It's difficult to log that information into a database or use it for statistical process control. Without numerical data, long-term trends in color can be missed. Instruments, on the other hand, yield numeric data that can be recorded and analyzed. They enable color control charts, specification limits, and capability analysis. Visual methods provide none of these quantitative quality control tools. Additionally, if multiple facilities are producing the same product, visual matching across plants is nearly impossible to standardize, whereas if all plants use the same model of spectrophotometer hitched to the same color standard, they can achieve very tight inter-plant agreement. This is crucial for large companies that want uniform product color regardless of manufacturing location.
- Limits of Visual Standards: Historically, the tomato industry used physical standards for visual comparison – for example, prior to 1972, USDA inspectors

would compare tomato products to USDA developed 'soft' standards, actual tomato paste standards developed by the USDA. Later, colored ceramic tiles (like the BCR No. 400 "tomato red" tile in Europe or the USDA/UCD tomato paste tile in the US) became reference standards for color. An analyst would visually compare the sample's color to these tiles. While this was a step towards consistency, it still suffered the issues above (lighting, perception differences). Moreover, not everyone would interpret the comparison the same way – how close must the sample be to the tile to be acceptable? Such visual comparison methods are now considered *archaic* and nearly obsolete in high-throughput operations. The USDA today encourages the use of instrumental measurement over visual methods, because instruments can directly read the sample and even "hitch" (calibrate) to the standard tile's known values for objective comparison. In essence, instrumental methods take the guesswork out of using color standards by providing a clear numerical match or deviation.

- Color Control: From a control standpoint, if color starts to drift in a process, visual methods are often too slow or imprecise to catch it early. For example, a slight browning due to a steam boiler issue might not be noticed until it becomes pronounced. By that time, a large volume could be off-color. Instruments can detect even small drifts in color parameters (a drop in the a/b ratio, or a decrease in L indicating darkening) immediately, prompting investigation before it worsens. Visual inspection usually works on a go/no-go basis with a relatively coarse threshold, whereas instruments support continuous improvement by enabling tighter tolerances.

Considering these challenges, it's clear why the tomato industry has largely moved toward instrumental color control. Variations in individual color perception and the time consumed by visual processes have made [old visual methods] nearly obsolete. Most regulations and company QA protocols now require systems that minimize human judgment in color grading.

Spectrophotometers and colorimeters address these visual evaluation challenges by offering consistency, objectivity, speed, and data-centric control. The result is superior color consistency in products, reduced risk of human error, and overall, more efficient quality control. In modern tomato processing facilities, the role of the human observer is largely to operate and verify the performance of the instruments, rather than to make color decisions unaided.

Market Segments and Distribution: Industrial/Bulk vs. Retail/Consumer-Packaged

Tomato products can be broadly divided into two market segments: industrial/bulk products and retail/consumer-packaged products. While the fundamental importance of color quality is high in both segments, the way color measurement is applied can differ based on each segment's priorities and distribution channels. Here, we contrast the two segments and illustrate how color measurement is critical for various product types – tomato paste, ketchup, sauce, juice, and diced tomatoes – in each.

- **Industrial/Bulk Segment:** This segment includes tomato products that are produced in large volumes and sold in bulk (often B2B) to food manufacturers, foodservice companies, or as ingredients for further processing. Examples are tomato paste in drum or tote containers, tomato puree or concentrate, bulk tomato juice concentrate, and bulk packs of diced tomatoes (e.g., 300 gallon totes or #10 foodservice cans). In this segment, meeting standardized color grades and specifications is paramount, because color often determines the product's grade and price. Producers of industrial tomato products rely on color measurements to ensure their product meets the contract requirements (such as "USDA Grade A tomato paste" or a specified minimum color score). For instance, a bulk tomato paste supplier will use spectrophotometers to measure the Tomato Paste Score (TPS) or the a/b ratio of each load. If the score is high enough, the paste can be sold as "Fancy" grade at a premium; if not, it may be sold as lower grade or blended. Color measurement in the industrial segment is thus closely tied to quality grading and regulatory standards. Instruments like the ColorFlex L2 Tomato are used to generate official color certificates that accompany shipments, giving buyers confidence in what they're receiving. Industrial buyers (like ketchup manufacturers) will often double-check color on receipt, so having both supplier and buyer using the same measurement methodology (same instrument type and tomato tile) ensures seamless acceptance.

Another aspect in bulk distribution is process optimization – industrial processors use color data to drive process decisions that maximize yield of top-quality product (as seen in the case study where a paste producer improved Grade A yield by adjusting processes based on color readings). Bulk tomato products usually undergo thermal processing (evaporation for paste, etc.), and color can degrade if parameters aren't optimal. By monitoring color in-line or at-line, industrial producers can avoid overcooking (which causes browning) and ensure the final bulk product has the desirable bright red color. In summary, in the industrial segment, color measurement is about standardization, grade classification, and meeting precise specifications for large-volume trade.

For specific products in this segment:

- *Tomato Paste (Bulk)* – Measured for TPS/a/b ratio to assign USDA grade. Contracts may specify a minimum a/b ratio (e.g., ≥2.1). Paste is typically shipped in 55-gallon drums or larger containers; each is often sampled and tested. Color data is used for pricing adjustments if needed (e.g., if color falls short, it might be sold as a lower grade).
- *Tomato Juice Concentrate* – Often used by other food companies (e.g., soup or beverage makers). It is measured for Tomato Juice Score (TJS) to

ensure it was made from good ripe stock. If the color is off, it might indicate the need for blending concentrates from different batches to achieve a consistent final color when reconstituted.

- *Diced Tomatoes (Industrial packs)* – Large foodservice cans of diced tomatoes or totes for sauce manufacturers rely on consistent redness. Processors measure color (perhaps via an average slurry method) to ensure the dice meet a "Type" or grade (there are often standards for color uniformity in diced tomatoes used by, say, pizza chains in bulk). If too many yellow/green pieces are present, the color reading (like a lower a value) will flag it. Some bulk buyers require a minimum red color score or absence of green units as part of specifications.

- Retail/Consumer-Packaged Segment: This segment includes tomato products that are packaged for direct sale to consumers under brand names – e.g., bottled ketchup, jarred or canned pasta sauce, canned tomato sauce and paste (small cans), bottled/canned tomato juice, and canned diced or whole tomatoes for retail. In this segment, brand consistency and consumer appeal are the driving factors for color control. Every jar or bottle on a store shelf needs to meet the brand's standard of appearance, as color is a key part of the product's identity (consumers unconsciously associate a certain shade with a brand's quality and flavor). Color measurement is applied at multiple points to maintain this consistency. Unlike the industrial segment, where the focus is meeting a public grade standard, retail producers often define their own internal color standards that might be even tighter than USDA grades to ensure a uniform product. They may use spectrophotometers to establish a "golden batch" color profile and then require all batches to match it within a small ΔE tolerance.
- Packaging and distribution in this segment also influence how color is perceived: for example, ketchup is in a translucent squeeze bottle where the

consumer can see the product, so any variation might be noticed. Canned goods hide the product until opening, but consistency is still checked to avoid surprises. Retail manufacturers use color data in quality control release decisions – a batch not meeting color spec might be held back or remixed before packaging to avoid off-color products reaching stores. They also often perform shelf-life studies where color is measured over time to ensure the product doesn't discolor before the end of its shelf life (this can be particularly important for things like jarred pasta sauces – if color darkens or separates in the jar over months, that's a problem). Instruments help quantify even subtle changes, so packaging and formulation can be adjusted (for instance, adding an antioxidant or using light-resistant packaging if color fade is detected).

In the retail segment, the marketing and product development teams also get involved with color measurement. For example, during R&D of a new ketchup formula, they'll target a specific L,a,b that scored best in consumer tests. Spectrophotometers enable hitting that target in scale-up. Or, if a company wants to benchmark a competitor's tomato soup color, they can measure it and compare to their own, quantifying differences that might correlate with consumer preference. In essence, color measurement becomes part of quality assurance and product design.

For specific products in this segment:

- *Ketchup (Retail)* – Color measurement is used to maintain the iconic look of the brand. As discussed, each batch is typically tested, and any deviation beyond a tight tolerance would trigger corrective action. Because ketchup is often made from tomato paste plus other ingredients, slight differences in source paste color can be evened out during ketchup manufacturing – but only if noticed. Thus, having a spectrophotometer in the ketchup plant ensures they can adjust (for example, a bit more tomato solids or a dash of paprika for color in an emergency) to preserve the standard color. Ketchup brands also ensure consistency across production plants: if one plant in Asia and another in the US make the same ketchup, they both use the same color standards and instruments to hit identical color, so that a bottle bought in New York looks the same as one in California.

- *Retail Tomato Sauce/Pasta Sauce* – These can vary in recipe (some are chunkier, with herbs visible), but each brand has a characteristic color tone (some may be bright red, others more orange-red depending on spices). Companies measure the sauce (often pureeing a sample to read it uniformly) to control batch color. Particularly, if a sauce includes other vegetables (onion, bell pepper) that can affect color, instrumentation helps ensure the final blend still falls in the desired color range. Consumers might associate a very dark sauce with overcooking or a very pale sauce with dilution – both negative impressions – so the manufacturer ensures through QC that the color stays appetizing and on-brand.
- *Tomato Juice (Retail beverage)* – Here, color is both a quality and marketing factor ("rich red tomato juice" is appealing). Companies measure the juice to monitor any browning (which could indicate vitamin C loss or oxidation). Since retail juice might be in clear bottles or cans with imagery, the color standard is maintained so that every batch is equally vibrant. A notable point: some tomato juices or blends might have color specifications to meet (like a certain minimum juice color if labeled as tomato juice per regulations). Instrumental color ensures compliance with such standards (which are often based on visual or instrument measures).

- *Canned Diced/Whole Tomatoes (Retail)* – Consumers opening a can of diced or whole peeled tomatoes expect mostly red pieces. Processors use color sorting during production to remove green tomatoes, but final QC may involve measuring the drained contents color or performing visual counts of off-color pieces. Spectrophotometers can assist by quantifying overall redness. While a consumer might forgive one green tomato in a can, too many will cause complaint. Thus, the color measurements (or at least consistent color processes) in the plant aim to minimize can-to-can variation. Additionally, packers often produce different styles (regular vs. "with basil" etc.); they check that adding herbs or calcium (which can slightly yellow the liquid) doesn't drift the color outside acceptable consumer range.
- *Salsa (Retail & Foodservice) –* Consumers expect salsa to present as a rich, appetizing red base, often with visible green peppers, onions, or herbs as intentional inclusions. Processors use color control to ensure the tomato portion dominates visually, avoiding washed-out or overly brown tones that suggest poor quality or over-processing. Spectrophotometers can quantify the redness and consistency of the tomato base, helping plants balance the natural variability of raw ingredients like peppers and spices. While small differences in shade from batch to batch may be tolerated, excessive dullness, browning, or off-color pieces can reduce shelf appeal and trigger consumer rejection. In addition, variations caused by added ingredients (cilantro, jalapeños, vinegar) are monitored to ensure that the finished salsa stays within an acceptable visual range, maintaining brand consistency across jars, tubs, or single-serve packs.

In comparing distribution: Industrial products often go through commodity distribution channels and might even be inspected by government graders for color, whereas retail products go through retail distribution where consistency and brand reputation are at stake on the supermarket shelf. In both cases, spectrophotometers are the guardians of color quality, but the rationale might be phrased differently: "meeting spec and grade to ensure contract fulfillment" (industrial) versus "delighting consumers and protecting brand uniformity" (retail).

It's worth noting that many companies straddle both segments. For example, a big processor may sell paste in bulk (industrial) and use that paste internally to make retail pasta sauce. For them, an integrated color quality system is crucial – they'll measure color at the paste stage (industrial focus) and again at the finished sauce stage (retail focus). The good news is the same spectrophotometer can serve both purposes, and the data from one stage can inform the other. If the paste was slightly low in redness, the sauce plant knows they might need to adjust the recipe slightly to achieve the target consumer color. This interplay is a clear demonstration of how instrumental color control facilitates communication across the supply chain.

In terms of distribution teams and sales (since the audience includes internal sales/distribution teams), understanding these segments helps tailor the value proposition of color measurement devices or protocols. For bulk tomato product sales, sales teams can emphasize how consistent color (achieved by instruments) means fewer rejections and premium grading– a selling point to ingredient buyers. For retail product distribution, they can highlight that the brand invests in state-of-the-art color quality control (instruments and standards) to ensure every jar or bottle a distributor receives will meet consumer expectations, thereby reducing customer complaints and returns. Distribution personnel also benefit from knowing that products are monitored; for instance, if a batch with a slight color deviation is knowingly shipped (still within spec but on the edge), they can proactively inform retailers of the quality checks done, maintaining transparency.

To summarize, industrial/bulk and retail segments both heavily rely on color measurement, but for slightly different end goals: the former to satisfy objective grade/spec requirements and facilitate B2B trade of tomato products, and the latter to ensure a consistent, appealing product reaches the end consumer, thereby supporting brand integrity. In both segments, spectrophotometers like the ColorFlex L2 are invaluable – they provide the quantitative color data that underpins quality control programs, whether those programs are aimed at hitting USDA grade standards or a company's own internal color signature for a product. The versatility of modern instruments allows the same device to generate data relevant for both contexts (e.g., reporting a USDA grade for internal use, and simultaneously checking ΔE against a proprietary standard). This unifying role of instrumental color measurement across segments helps tomato product companies maintain color harmony from farm to table.

History of HunterLab's Role in Tomato Color Standardization and the Tomato Tile Reference

HunterLab's history is deeply intertwined with the development of objective color measurement in the tomato industry. Over the decades, HunterLab has pioneered the methods and reference standards that have become the benchmarks for tomato color quality. This historical journey spans from the invention of color scales to the creation of durable color standards like the famous "Tomato Tile."

Origins – Hunter's Color Scale and Early Instruments: In the 1950s, Richard Hunter, founder of HunterLab, introduced the Hunter L, a, b color scale—one of the first systems to quantify color in a way that closely aligned with human vision. This breakthrough quickly found applications across many industries, including food. By the 1960s and 70s, the tomato processing industry began looking for more objective methods of evaluating color to supplement or replace subjective visual grading. Until then, processors relied on comparators such as the Munsell Tomato Color Discs or the judgment of experienced inspectors.

In the late 1970s, researchers at the University of California, Davis, working with the USDA, initiated a collaborative effort to correlate these visual assessments with instrumental readings. HunterLab's instruments, particularly the D25 Tristimulus Colorimeter, were at the center of this transition. The D25-D2 and D25A models, equipped with 45°/0° geometry, proved robust and well-suited for food applications.

A major milestone came in July 1980 with the publication of *"Color Scoring Tomato Products Objectively"* by Marsh et al. (UCD), which established equations for calculating tomato color scores (TPS, TCS, etc.) directly from instrument data. These equations were based on HunterLab values, and the USDA formally adopted the D25 series as its reference devices. The USDA even commissioned Tomato Reference Meters from HunterLab, with the D25A quickly becoming the gold standard for tomato color evaluation. In effect, the modern color scores for tomato paste, sauce, ketchup, and juice were originally defined through measurements on HunterLab equipment.

The Tomato "Soft Standard" and Birth of the Tomato Tile: Prior to instruments, one method to ensure consistency was using physical reference standards. The USDA/UC Davis Tomato Paste Soft Standard was one such reference: it was literally a canned tomato sauce/paste with known color attributes that could be purchased by processors to "standardize" their visual comparison. A lab technician could compare their product's color to this official canned standard. However, a canned product is not ideal as a standard – it can spoil once opened, it's not reusable for long, and it can be messy. Seeing this challenge, HunterLab took the initiative to create a stable, easy-to-use color standard for tomato products. They developed a porcelain enamel steel tile in a specific "tomato red" shade that closely matched the UC Davis soft standard's color. This was the original HunterLab Tomato Tile. HunterLab would "hitch" (calibrate) each tile to the soft standard's values using their instruments, so that a processor could buy the tile and use it to standardize their colorimeter without having to handle perishable tomato sauce. Essentially, HunterLab provided a durable surrogate for the tomato paste standard.

By introducing the tomato tile, HunterLab greatly simplified objective color grading for industry labs – instead of preparing and maintaining their own reference purees, they had a ready-made tile that they could measure daily to ensure their instrument read consistent values, and also to transfer color values from one instrument to another (inter-instrument agreement). This innovation significantly improved the practicality of spectrophotometric grading, and many processors adopted the practice of hitching to the HunterLab tomato tile. The USDA and UC Davis also embraced tiles as a replacement for the old colored glass/plastic discs by the early 1980's.

European Tomato Tile (BCR-400) and Global Standardization: Across the Atlantic, a similar move happened in 1991. The Commission of the European Communities, through BCR (Bureau of Community Reference, later IRMM), commissioned a ceramic tile standard (BCR No. 400) that represented the color of ripe plum tomato. These tiles were manufactured by Ceram Research (UK) with a high-lead red glaze. Notably, all BCR-400 tiles were measured on a HunterLab D25 at the time of production, and assigned Hunter L, a, b values (C/2°) in 1990's. This underscores that HunterLab instruments were the reference backbone internationally as well. The BCR-400 tiles were individually certified and distributed to labs as a color reference for tomato paste products in Europe. For years, both the American tile and the European tile coexisted, each with slightly different color (the European one mimicked a plum tomato, which was a bit different shade than the US one). Companies trading internationally sometimes had both and would ensure their instruments could align with either standard as needed.

Challenges and HunterLab's New Tomato Tile: By the early 2000s, a new challenge emerged: the pigments used in the original HunterLab tile and the BCR-400 tile contained lead and other heavy metals, necessary at the time to achieve the deep red hue. Environmental and safety regulations from the EU and EPA forced these materials to be phased out, and by around 2015 the supply of new tiles in the original color had run out. While existing tiles could continue to be used, companies without them—or those needing replacements—had no way to source new reference standards.

Recognizing this critical gap, HunterLab developed a new Tomato Reference Standard Tile using modern, environmentally friendly pigments. While not a perfect chemical duplicate of the BCR-400, it was carefully formulated to be the closest possible visual and instrumental match. To ensure cross-user consistency, HunterLab employed a Master ColorFlex EZ Tomato spectrophotometer and hitched all new tiles to a common master, calibrated by NIST in Hunter L, a, b C/2° values. This process guaranteed that each new tile would produce essentially the same readings across HunterLab instruments.

HunterLab advised users that if they adopted the new tile, all instruments within a data-sharing network should also switch, since slight differences compared to older tiles—such as a small shift in the a/b ratio—could be noticed. In fact, HunterLab published comparative data showing how a tomato paste sample's TPS or a/b ratio varied slightly depending on whether it was hitched to an old USDA tile, the BCR-400, or the new reference. The differences were minor, but industry consensus favored consistency: adopting one common tile ensured alignment across processors. Today, HunterLab remains the only provider of a tomato reference tile with lineage back to the original USDA and BCR standards—continuing the chain of calibration that defines modern tomato color measurement.

This continuity underscores HunterLab's historic role in color science. In the 1950s, at the request of USDA scientists such as J.N. Yeatman, Richard Hunter pioneered a tomato colorimeter and the mathematical framework that allowed objective categorization of tomato products. This was the first time in the world that food color could be measured instrumentally rather than judged by eye, and it marked a turning point not only for tomato processors but for color science as a discipline. HunterLab has built on that foundation ever since, advancing both the mathematics and the instrumentation—culminating today in the ColorFlex L2 Tomato, the most precise and user-friendly spectrophotometer for tomato products.

Ongoing Role and Influence: Beyond hardware, HunterLab has continually partnered with the USDA to validate equations, update acceptable instruments, and ensure seamless continuity between generations. When new models such as the ColorFlex 45/0 or LabScan XE were released, HunterLab collaborated to confirm that official USDA tomato score equations applied correctly. Even in 2008, when the USDA evaluated a competitor (the Minolta CR-410), it was HunterLab's LabScan 5100 that served as the benchmark reference.

HunterLab's contributions also extend to education and standardization. Through application notes, knowledge base articles, seminars, and participation in ASTM and ISO committees, HunterLab has guided best practices for food color measurement. This consistent engagement has helped processors understand how to establish hitch standards, perform reliable measurements, and maintain global consistency in reporting tomato scores.

Legacy and Continuity: HunterLab's stewardship has been pivotal: they created the first tomato instruments, defined the original quantitative scales, developed the physical standards (tiles) to maintain them, and updated those standards as technology and regulations evolved. The Tomato Reference Tile embodies this legacy—connecting today's ColorFlex L2 Tomato back to the USDA and UCD standards established decades ago.

This unbroken calibration lineage means that a TPS of 50 measured today on a ColorFlex L2 is directly comparable to a TPS of 50 measured more than 30 years ago on a D25. For processors, this continuity is more than technical—it is a guarantee of trust. Many veteran quality managers recall starting their careers with “the old Hunter” and now rely on “the new Hunter,” confident that the standard has not shifted.

HunterLab’s historical and ongoing leadership ensures that the tomato industry continues to operate with one clear, objective, and universally recognized color standard.

Best Practices for Instrumental Color Measurement in Tomato Manufacturing

Implementing spectrophotometric color measurement in tomato product manufacturing requires attention to certain best practices to ensure accuracy and meaningful results. Below are key best practices, from instrument setup and calibration to sample preparation and data handling, that tomato processors should follow:

1. Use the Appropriate Geometry and Calibration Standards: Tomato products, being typically opaque or semi-opaque with surface texture, are best measured with 45°/0° geometry instruments (or equivalently 0°/45°). This geometry views color similarly to the human eye by excluding specular reflections, which is why it has become the industry standard for tomato color evaluation. Instruments like HunterLab’s ColorFlex L2 series 45/0 optics and should be used in this mode for tomato products. Integrating-sphere (d/8°) instruments can measure color too, but may include gloss and view the sample differently, often requiring separate calibration formulas to correlate to the standard 45/0 results. Thus, it’s a best practice to use the geometry that the official methods and historical standards are based on (which is 45/0).

Additionally, always standardize (calibrate) the instrument at the start of each day or shift using the supplied white calibration tile and black trap (or black glass). This ensures the spectrophotometer's baseline is correct. For tomato measurements, one extra step is recommended: use a Tomato Color Reference Tile as a hitch standard. HunterLab provides a special tomato red tile (calibrated and traceable to the original USDA/UCD and BCR standards) for this purpose. The process, often called "hitching," involves reading the tomato tile and adjusting the instrument so that it reports the tile's known standard values (under illuminant C/2°). This effectively standardizes the instrument's color scale specifically for tomato products. The benefit of hitch standardization is improved agreement between instruments and over time – if every lab uses the same tile, their TPS or a/b readings on the same sample will align closely. Best practice is to hitch to the same tile type across all instruments in your company (e.g. all use the new HunterLab Tomato Tile). If you still have an older USDA/UCD tile or a BCR-400 tile in use, note that they have slightly different assigned values; mixing tile types can introduce bias. It's recommended to transition all locations to the modern, lead-free HunterLab tile to maintain consistency going forward. In summary: calibrate daily, and hitch to the tomato reference tile for tomato color scales.

2. Sample Preparation and Presentation: How the sample is prepared and presented to the instrument critically affects the accuracy of color readings. Tomato products come in different forms, so there are best practices for each:

- *Tomato Paste/Purée:* Use a standardized glass sample cup (usually ~64 mm diameter and a few millimeters deep). Fill the cup with the paste so that it is packed and flush to the top, avoiding air bubbles or gaps (bubbles can scatter light and alter readings). A consistent fill depth is important – UCD guidelines suggest marking a fill line on the cup to ensure the same depth each time. Place an opaque cover or backing (often a white ceramic backing tile or the instrument's port insert) behind the cup when measuring so that no ambient light or transparent effects influence the reading. Ensure the paste is homogeneously mixed; if the paste has settled or has darkened top layer from exposure, stir it well before sampling. Also, measure paste at room temperature. Temperature can slightly affect color (hot paste can appear less viscous and maybe slightly different in gloss), and sweating/condensation on a cold sample can interfere. So, allow samples to cool to a consistent temp before reading.

- *Ketchup/Tomato Sauce:* These are more fluid. They should also be measured in a sample cup or an optically clear petri dish. Often a path length of about 10 mm of product is sufficient to make it optically opaque (no light passes through). For sauces with particulates (like herbs or chunks), blend them or remove the chunks to measure the sauce base, or take multiple readings including chunks to average the appearance. Always cover the sample (many instruments come with a light cover) during measurement to exclude room light. Since ketchup can be messy, it's useful to have a spill-resistant sample holder – the ColorFlex L2, for example, has a sealed, spill-proof sample compartment design to contain any overflow. Cleaning any residue from the measurement port and cup between samples is essential to prevent cross-contamination of color (a bit of leftover ketchup in the port could affect the next reading).
- *Tomato Juice:* If measuring in reflectance mode, use a small cuvette or cup and place a white backing behind it (some instruments have a special transmission chamber, but 45/0 devices typically do reflectance). Make sure no seeds or large pulp pieces stick to the glass in the measurement area, as they could influence readings. Degas or avoid bubbles in juice samples as well.
- *Diced/Whole Tomatoes:* For a quick assessment, one can drain off liquid and spread the pieces in a shallow dish that covers the measurement port. Taking an average reading of multiple orientations (stirring between reads) can

account for variability. Alternatively, as mentioned, blending to a coarse puree can give a representative color number. In any case, define a consistent method in your SOP: e.g. "Blend 100 g of diced tomatoes for 30 seconds and fill cup to measure." Consistency is key for comparative data.

Additionally, always ensure the sample completely covers the instrument's measurement aperture. If using a large aperture (like 2-inch on Agera), you need enough sample to cover that area uniformly. If the sample doesn't cover, you might get mixed signals with background. If sample amount is limited, switch to a smaller aperture.

3. Instrument Maintenance and Verification: Keep the spectrophotometer in calibrated condition. Protect it from extreme temperature or humidity swings on the factory floor – most are designed for lab/at-line use within certain environmental conditions (often around 10–38 °C and below 85% RH). Clean the optical glass (or lens) and reference tiles regularly per manufacturer instructions – tomato products can stain if left on the white tile, so wipe it clean after each use with a soft, lint-free cloth and solvent if necessary. It's good practice to periodically verify performance by reading color standards or tiles with known values. For example, measure a stable red ceramic tile (other than the hitch tile) daily or weekly and log the readings to ensure the instrument is stable (this can catch any drift early). Utilize the built-in diagnostics if available – the ColorFlex L2 has on-board diagnostic health checks to ensure it's performing at peak, continuing HunterLab's reliability legacy. If any diagnostic fails or the readings of standards deviate beyond tolerance, recalibrate or service the instrument before relying on it for production decisions.

4. Leveraging Tomato-Specific Scales and Software: Use the instrument's specialized scales for tomato products. Modern instruments targeted at the tomato industry come with firmware that directly computes indices like TPS, TCS, TSS, TJS, a/b ratio, Fresh Tomato Color Index, and Lycopene Index. It is a best practice to use these pre-

programmed scales because they apply the correct official formulas for you, reducing chances of calculation errors. For instance, rather than manually calculating TPS from L, a, b (which for different instruments might require different coefficients), you can trust the instrument's "Tomato Paste Score" reading, knowing it's using the USDA-approved formula for that device. Ensure your team is trained on selecting the correct "Product Setup" on the device – e.g., one setup for paste (giving TPS), another for ketchup (TCS), etc. HunterLab's tomato-focused instruments often label these clearly or even have them as the default options for a "Tomato meter" mode.

Additionally, take advantage of software for data management. Using quality control software (such as HunterLab's EasyMatch Essentials software) can help store and organize color data for each batch. Set up product standards in the software – for example, define the target color values for your "Brand A Ketchup" and set tolerances (like ±ΔE or specific a/b range). Then each time you measure a sample, the software can automatically flag Pass/Fail against those tolerances. This ensures no subjective interpretation of the readings – it's immediately clear if something is out of spec. The software can also generate reports and trends which are useful for audits and continuous improvement. Embracing these digital tools maximizes the value of instrumental measurement.

5. Establish Sampling Protocols and Frequency: Decide how often and how many samples to measure, and stick to the protocol to ensure consistent monitoring. For example, a best practice might be: for every batch (kettle) of ketchup, measure 3 subsamples and average the color results to represent that batch. Or for continuous processes like tomato paste from an evaporator, take a sample every 30 minutes for color measurement. The idea is to gather enough data to catch variability but not so much that it overwhelms. Many processors will measure the start, middle, and end of a production run to ensure color stayed in control throughout. The data can reveal if, say, color drifts as equipment warms up or as raw material bins switch. By adhering to

a defined sampling plan, you ensure that no batch ships without a color check and that the data is comparable across batches.

6. Training and Procedures: Train the quality control staff not just on instrument operation, but on proper sample handling and data interpretation. Everyone running the tests should follow the same procedure – this reduces operator-induced variation. For instance, an SOP might specify: "Mix sample for 1 minute, fill sample cup to brim, tap gently to remove air bubbles, cover and measure. Record the average of two readings rotated 90° between readings." Such detail ensures repeatability. Training should also include instrument calibration steps, cleaning, and what to do if a reading seems suspect (e.g., re-measure, check calibration). Since the instruments are simple to use (ColorFlex L2, for example, is designed with a modern touchscreen interface for intuitive operation and even offers an integrated wizard for new users), training is typically straightforward. However, reinforcing why each step matters helps maintain diligence – e.g., explaining that not using the opaque cover could let ambient light in and skew results, etc.

7. Data Utilization and Feedback: Lastly, make color data a living part of your quality control system. Simply measuring and recording is good, but acting on the data is what closes the loop. Establish acceptable ranges for each product's color metrics based on customer requirements or internal standards. When a measurement is out of range, there should be a defined response – such as informing production to hold the batch, adding more concentrate to adjust color, or investigating equipment. Some companies implement Statistical Process Control (SPC) on color, meaning they'll track the mean and variation and look for trends or shifts. If, say, the average a/b ratio for tomato paste is gradually declining over a week, it might signal a change in incoming tomatoes (perhaps later season tomatoes with slightly different color), and they might tighten the sorting or add more of a color enhancer if allowed (though typically not, as tomato products usually rely on natural color). The key best practice is to integrate the instrument data into decision-making. Many modern instruments can even be networked or set to automatically email results, so the production supervisors get immediate alerts if color is off. This kind of connectivity (available on devices like Agera and ColorFlex L2, which have multiple communication options: USB and Ethernet ensures the color measurements feed into the plant's quality information systems. Connecting with LIMS (Laboratory Information Management Systems) or SPC software is also recommended for seamless data flow.

By following these best practices, tomato processors can make the most of spectrophotometric color measurement. The result is high confidence that every product leaving the factory has the intended appearance, tighter control over the manufacturing process, and credible data to demonstrate quality to stakeholders (whether internal management, customers, or regulators). Instrumental color measurement, when done right, becomes an indispensable part of the overall quality management system in tomato product manufacturing, turning what was once a subjective attribute into a scientifically controlled parameter.

HunterLab's ColorFlex L2 – Detailed Feature and Benefit Summary

The ColorFlex L2 Tomato is a next-generation compact benchtop spectrophotometer that builds upon the legacy of the ColorFlex EZ Tomato (a widely used model in the industry). It uses 45°/0° annular illumination geometry, the industry-preferred geometry for tomato color.

The "L2 Tomato" comes pre-loaded with a comprehensive set of tomato-specific indices and scales, including:

- Tomato Paste Score (TPS)
- Tomato Sauce Score (TSS)

- Tomato Catsup Score (TCS)
- Tomato Juice Score (TJS)
- Fresh Tomato Color Index (FTCI)
- a/b ratio
- Lycopene Index

This means that, out of the box, it can measure any form of tomato product and directly report the relevant quality metrics – a significant convenience for processors.

User Interface and Workflow

The ColorFlex L2 has a modern touchscreen interface (7-inch color display) with a tablet-like user experience. It is designed to be used standalone, with large onboard storage and processing, so no external PC is required for routine operation. Users can optionally connect a monitor, keyboard, or mouse if they want a larger display or more PC-like interaction, but most will find the built-in interface sufficient.

The instrument includes Essentials 2.0 software, which allows quick measurements, averaging, pass/fail criteria, and analysis of spectral data sets with ease. It guides users with an intuitive wizard, making startup and training straightforward – an important feature for plants with frequent operator turnover.

Ruggedness and Maintenance

The ColorFlex L2 Tomato is built to withstand demanding plant and lab environments:

- Spill-proof sample compartment protects optics from splashes and accidents.
- Compact footprint saves bench space and allows the instrument to be easily moved between labs or production lines.
- Lightweight portability enables flexible deployment.

The device also features a built-in camera for sample viewing and screen recording. This helps ensure samples are positioned correctly, and recorded images can be stored for documentation and traceability.

Illumination and Calibration

The ColorFlex L2 uses a long-life LED light source, providing stable, full-spectrum illumination without the maintenance issues of older halogen-lamp instruments. Benefits include:

- No frequent lamp replacements
- No warm-up drift
- Support for multiple illuminants and observers (C/2° is the standard for tomato, but D65/10° and others are available for broader applications)

The instrument is delivered with the HunterLab Tomato Reference Tile and values, ensuring accuracy and consistency. It traces its performance directly back to recognized tomato color standards.

Connectivity and Data Management

- USB ports for flash drives, printers, keyboards, or peripherals
- HDMI output for external monitor connection
- Ethernet for network connectivity and LIMS/SPC integration
- Internal storage for thousands of readings

These options allow seamless data transfer and integration into plant or corporate QC systems.

Physical Design

- Compact benchtop footprint (~8″ W × 13″ D)

- Approximate weight: 12–15 lbs
- Rugged construction with a sealed, spill-proof design
- Chemical-resistant housing and durable glass touchscreen

Diagnostics and Calibration Aids

- Automatic diagnostic checks on startup
- Provided with the HunterLab Tomato Calibration Tile and certificate, standard white tile, and black glass
- Guided hitching to ensure correct setup for tomato-specific scales

Intended Users

The ColorFlex L2 Tomato is purpose-built for QA/QC labs at tomato processing plants, bulk tomato product producers, and packers who need robust, easy-to-use, routine color checks. It is also suitable for R&D labs, but its design and features are optimized for routine operation and widespread use, including by technicians and operators.

It offers the best value as a dedicated tomato color solution – compact, reliable, accurate, and tailored specifically to the needs of tomato processors.

Why the ColorFlex L2 Tomato is Best-in-Class

The ColorFlex L2 Tomato was developed with decades of HunterLab's experience in the tomato sector. It ensures superior consistency and accuracy, thanks to its 45/0 geometry and calibration to tomato-specific standards. Unlike generic color instruments, it speaks the language of tomato processors, reporting direct readings in tomato industry quality units (TPS, TSS, TCS, etc.) and eliminating guesswork.

For companies seeking a dedicated, accurate, and easy-to-use tomato color measurement solution, the ColorFlex L2 Tomato stands as the proven industry workhorse – compact, cost-effective, and precise, while maintaining HunterLab's trusted reputation for performance and support.

Case Studies Highlighting ROI and Quality Improvements Using Instrumental Color Measurement

The implementation of instrumental color measurement can yield significant returns on investment (ROI) for tomato product manufacturers. Below we highlight a couple of case examples (composite and anonymized from industry scenarios) that demonstrate how using spectrophotometers led to measurable quality improvements and economic benefits.

Case Study 1: Tomato Paste Producer Improves Grade Yield and Reduces Downgrades

A large tomato paste processing company (supplying bulk paste to ketchup and sauce manufacturers) invested in upgrading from a primarily visual grading process to an instrument-based color quality control process. They purchased several HunterLab ColorFlex instruments and standardized their entire operation on instrumental Tomato Paste Score (TPS) measurements.

- Initial Situation: The company processed thousands of tons of tomatoes each season. Previously, they relied on experienced graders to visually compare paste samples to the USDA tomato color standards (tile and color fan) to assign grades. On average, about 15% of their output was designated as off-grade (Grade B or below) due to color not meeting Grade A standards. Some of this was truly due to raw material issues, but they suspected that inconsistency in visual grading might also be causing batches to be *under*-graded. Additionally, when customers disputed a shipment's color, there was no quantitative data to back up their grading, occasionally resulting in price discounts or returns.

- Intervention: With the new spectrophotometers, the company implemented instrument readings at three critical points: incoming fruit (to decide if loads needed separation), in-process paste (mid-evaporation), and finished paste from each production run. They set a TPS target corresponding to Grade A and established an internal policy: if a batch's TPS was below the target, it would be automatically diverted to a lower grade product line or reprocessed if possible, whereas if it met/exceeded, it could be sold as Grade A. They also trained operators to adjust evaporator settings and blending based on real-time color feedback. For example, if mid-process measurements showed a slightly low TPS, they could extend concentration or mix in a small stream of a higher-color lot to bring the color up before final packing.
- Results: In the first season using instruments, the proportion of Grade A paste produced increased from 85% to 92%. This 7% improvement in top-grade yield was enormous in value: considering Grade A paste sold for about $50 more per ton than Grade B, on a throughput of 100,000 tons, this meant roughly $350,000 additional revenue. The improvement came partly from better process control (catching potential off-grade batches and correcting them) and partly from more accurate grading (some batches that visual graders marked as borderline Grade B were found by instrument to actually meet Grade A criteria, eliminating unnecessary downgrades). The instruments effectively paid for themselves within that one season just from this grade improvement.

Additionally, customer complaints about color virtually disappeared. Each paste shipment now came with a printed color report showing its TPS and a/b ratio, which matched what the customers measured on their end (since both were using the standardized tile and instrument method). This data transparency built trust and meant no more disputes; in one case, a customer's own check found a slightly lower TPS, but the supplier could demonstrate through calibration records and consistency that their measurement was accurate – it turned out the customer's instrument had not been hitched to the new tile, and once corrected, results matched. This kind of issue resolution was swift thanks to the common language of objective data.

- ROI and Intangibles: The ROI was calculated by the company's finance team: Instrument purchase and training: ~$100,000; Additional annual profit from improved grades: ~$350,000; thus ROI > 300% in the first year. In subsequent years, the benefits continued. Intangible gains included: improved customer satisfaction (measured via surveys – customers noted more consistent color year-over-year), improved operational efficiency (less rework of off-color product, saving labor and energy), and enhanced staff confidence (the QC team felt empowered by data – they could detect issues like slight raw material changes early and advise procurement accordingly). One unforeseen benefit: the data collected over the season allowed the company to identify which farm deliveries consistently yielded higher color paste. They shared this info with their growers, which led to agronomic adjustments (such as letting those fields mature slightly longer, or variety selection) that further boosted color in future harvests – a virtuous cycle initiated by having real measurements.

Case Study 2: Ketchup Manufacturer Reduces Waste and Ensures Brand Consistency

A ketchup production facility for a global brand implemented spectrophotometers on their filling line for in-process color monitoring and final QC release, resulting in reduced product waste and tighter color consistency across batches.

- Initial Situation: This plant produces multiple batches of ketchup daily. Ketchup color is a key attribute for the brand – consumer research showed that even slight differences in color could be noticed when bottles were side by side. Originally, the plant relied on recipe control and periodic lab checks. They had a colorimeter (an old HunterLab LabScan) in the lab but only used it for daily composite samples. Occasionally, a batch would come out slightly darker due to overcooking or ingredient variation; these would sometimes only be detected after filling, leading to either scrapping those batches or diluting them with a later batch (which risked two batches being off). It was estimated that about 1 in 20 batches had to be reworked due to color issues, costing time and ingredients. Also, when production was rushed or at night, sometimes no immediate color check was done, leading to a small risk of an off-color batch reaching the warehouse and needing hold/rework later.

- Intervention: The company upgraded to the ColorFlex EZ and later L2 in the QA lab and instituted a protocol of testing *every batch* of ketchup for color before release. More importantly, they implemented at-line testing: after the cooking stage and before bottling, a sample was taken to the lab (right next to production) and measured. The instrument's pass/fail tolerancing was configured with the brand's standard (they had a target L*, a*, b* for the ketchup and allowed only a very narrow ΔE tolerance). If the batch failed, it was flagged immediately. Over the first months, operators became adept at adjusting batches on the fly – for instance, if the color was slightly too dark (a lower L* and a slightly lower a/b), they might lighten it by blending in some portion from a parallel batch or by adding a bit more of a certain ingredient that was known to affect color (some ketchup recipes allow slight adjustment of sugar or vinegar which can influence color density).
- Results: The frequency of off-color batches requiring rework dropped from 5% (1 in 20) to about 1% (maybe 1 in 100). In a plant making 1000 batches a year, this meant avoiding 40-50 reworks. Each avoided rework saved not just product (valued ~$5,000 per batch in ingredients and packaging) but also avoided disruption in the schedule and extra labor/energy. They estimated annual savings of ~$200,000 from reduction in waste and overtime costs. Another

benefit was inventory reduction: previously, they kept a buffer stock of "rework ketchup" that could be blended into future batches, which consumed storage space and had to be monitored for food safety. With far fewer off-spec lots, they minimized that buffer, freeing up space and cash flow.

From a quality standpoint, after a year of instrument control, the color consistency (measured as batch-to-batch ΔE) improved dramatically. The company's specification was $\Delta E < 1$ between any two batches; originally they were sometimes near that limit, but now most batches were within ΔE ~0.3 of the target. This consistency was confirmed by a market survey: the brand conducted a test where they lined up bottles from different production dates and had a panel evaluate color uniformity – the panel noted virtually no distinguishable difference, whereas a year prior there had been occasional comments on slight differences. The brand's image of quality consistency was thus reinforced. The QA manager noted that the spectrophotometer became as indispensable as a thermometer in their process – it was a key metric they looked at for every batch, and it provided an "early warning system" for any process drift. For example, when a heating issue caused a slight browning, the color values picked it up before it got worse; maintenance fixed the steam jacket, and they avoided a potential large loss.

- ROI: The cost of the instrument was modest (around $15k) and training another few thousand; with $200k/year savings in rework, the ROI was over 1000% annually. Even more important to the company was brand protection – they viewed the instrument as insurance against a bad batch reaching customers. They calculated that avoiding a single recall or market withdrawal (which could happen if a badly discolored batch slipped through) saved potentially millions in brand damage and logistics. Thus, the investment in instrumental color control was deemed a huge success.

Case Study 3: Multi-plant Standardization and Data Integration (brief example): A tomato products company with three manufacturing plants introduced Agera spectrophotometers in each plant and used HunterLab's EasyMatch QC software networked through their LIMS. By doing so, they ensured that a Tomato Sauce produced in Plant A would have the same color as one from Plant B, within a delta E of 0.5, even without blending. They achieved this by all plants hitching to the same HunterLab tomato tile and exchanging a reference sample periodically that they all measured. The instruments' agreement was so good that when that company shifted production volumes between plants, there were no perceptible color differences. Management used this as a case to further centralize QC protocols – color data from all plants was monitored by a corporate quality group in real time, so if one plant started trending slightly off, they could intervene. This reduced inter-plant color variation by 75%. The ROI here was in operational flexibility – they could confidently supply big contracts from multiple sites, knowing the product would be uniform, thus utilizing capacity better and reducing shipping costs by producing closer to certain markets without worry of color mismatch.

These case studies illustrate that the benefits of instrumental color measurement go far beyond just "having nice numbers." They translate to fewer rejects, higher-grade product output, better use of raw materials, and labor savings – all of which have direct financial impacts. Moreover, they enhance quality in the eyes of customers and end consumers, which is harder to quantify but extremely valuable for maintaining market reputation. As one quality director put it: *"Our spectrophotometer paid for itself in months, but more importantly, it removed a lot of uncertainty. We sleep easier knowing our color is always under control."* This peace of mind and risk mitigation is a significant part of the ROI as well.

In conclusion, implementing spectrophotometers for tomato color control is an investment that yields multi-faceted returns: economic gains through improved efficiency and product value, quality gains through consistent and optimal product appearance, and

Conclusion

Color is a critical quality attribute for tomato products, and achieving consistent, high-quality color in sauces, pastes, juices, ketchups, and more requires a combination of sound measurement practices and the right tools. Through this white paper, we've explored how spectrophotometers enhance tomato product manufacturing by bringing scientific rigor to color quality control. We saw that color is not just about visual appeal – it correlates with important factors like lycopene content, ripeness, and even flavor perceptions, making it a proxy for overall product quality. The use of modern spectrophotometers allows processors to monitor and control this attribute with precision that human eyes cannot match, addressing the challenges of subjective visual evaluation with objective data.

We discussed the wide-ranging applications of color measurement across the production process: from sorting raw tomatoes for maximum redness, to in-process adjustments during concentration, to final QA of finished consumer products. In each of these steps, having quantifiable color information helps optimize the process and ensure the product meets either industry standards or brand specifications. We also looked at best practices – from instrument calibration with HunterLab's Tomato Tile standard to proper sample preparation – which are essential to obtain accurate and meaningful results. Adhering to these best practices means that the color data you base decisions on is trustworthy and reproducible.

While many color measurement devices exist, not all are equal for tomato applications. Instruments designed with tomato products in mind (like those from

HunterLab) offer tangible advantages: appropriate geometry (45/0), pre-programmed tomato indices, easy cleaning for messy samples, and traceability to recognized standards. Competing spectrophotometers can certainly be used, but they often require additional effort (like custom calibrations or formula conversions) to fit into the tomato color grading system. HunterLab's ColorFlex L2 exemplifies the best-in-class solutions – they marry technical excellence (accuracy, repeatability, advanced features) with practical usability (touchscreen interfaces, rapid measurements, stand-alone operation). ColorFlex L2 as we detailed, stands on the shoulders of HunterLab's long legacy in the field, and incorporate lessons learned over decades of helping customers measure tomato color.

Real-world case studies reinforced the value proposition of instrumental color control. Companies that implemented spectrophotometers saw concrete ROI in the form of increased product value (higher grade attainment), reduced waste and rework, smoother customer relations, and fortified brand consistency. Importantly, they also gained agility – the ability to catch and correct color issues early, which in a just-in-time manufacturing world is priceless. One cannot overstate the confidence that data brings: instead of guessing or reacting after the fact, producers can proactively ensure every batch is right, using color metrics as a guiding parameter. As one example showed, reducing off-spec batches from 5% to 1% can save hundreds of thousands of dollars and improve supply reliability. In an industry with tight margins and high volumes, these savings and quality improvements have a significant cumulative impact.

We also distinguished between the industrial bulk segment and the retail consumer segment. This illustrated that regardless of whether the product is destined for a factory or a family kitchen, color quality matters – albeit for slightly different reasons. Industrial customers demand adherence to grades and specs (which instruments deliver), while consumers expect consistent, appealing appearance (which instruments safeguard). In both arenas, spectrophotometers serve as the bridge between subjective expectation and objective assurance. They enable a common language of color quality from the tomato field all the way to the store shelf, thus uniting stakeholders on what “good color” means in numbers everyone agrees on.

Finally, we traced the history of HunterLab’s involvement in tomato color standardization, highlighting how instrumental the company has been in shaping the very standards used today. This historical perspective is not just interesting trivia – it underscores why HunterLab’s instruments and standards are so trusted. They have been there from the beginning, evolving the tools as the industry’s needs evolved (for instance, replacing soft standards with tiles, then updating tile technology when regulations changed. This commitment ensures that when you use a HunterLab spectrophotometer and their tomato tile, you are aligned with the de facto world standard of tomato color. It’s a lineage that gives meaning to the measurements; when your ColorFlex L2 reports a Tomato Paste Score, you can be confident that score is the same “language” that USDA inspectors, global tomato buyers, and processors across the globe understand and use.

In conclusion, enhancing tomato product manufacturing with spectrophotometric color control is both a technical upgrade and a strategic investment. Technically, it brings accuracy, consistency, and speed to color assessments. Strategically, it improves product quality, reduces risks, and can increase profitability by ensuring products meet the highest color standards (often unlocking better market grades or reinforcing brand premium status). For food processing professionals and quality control specialists, implementing these measurement strategies and tools means more robust process control and better end products.

HunterLab’s ColorFlex L2 emerges as standout solutions in this domain, offering tailored features for tomato products and embodying decades of industry expertise. By deploying such instruments and adhering to best practices, tomato product manufacturers can achieve a level of color quality control that was simply not possible with visual methods alone. This leads to a win-win: consumers get visually beautiful, appetizing tomato products with every purchase, and manufacturers gain efficiency, consistency, and credibility in their quality programs. In the vibrant world of tomato-based foods, where that perfect red hue carries so much significance, spectrophotometers are truly enabling producers to “measure up” to the highest standards of quality – bringing science, and a bit of the art of tomatoes, together in each delicious product.