

A Review on Standard Evaluation and Characterization Techniques for Lipstick Quality: Hardness, Breaking Point, Pay-Off, Melting Point, Spreadability, SPF Evaluation

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Abstract: Lipsticks are among the most widely used color cosmetic products, serving both functional and aesthetic purposes. Their formulation, quality, and sensory attributes significantly influence consumer acceptance and market competitiveness. To ensure safety, consistency, and performance, lipsticks undergo a comprehensive set of evaluation and characterization techniques. Parameters such as hardness, breaking point, pay-off, melting point, spreadability, and sun protection factor (SPF) evaluation are essential indicators of product stability, application behavior, and protective benefits. Hardness and breaking point testing reveal mechanical strength and resistance to fracture during application or handling. Pay-off measurement determines the intensity of color transfer, while melting point ensures resistance to temperature variations without compromising spreadability. Spreadability correlates with sensory perception, glide, and user comfort. In lipsticks containing UV-filter agents, SPF evaluation is critical to validate photoprotection claims and ensure safety against UV exposure.

This review provides a detailed discussion on standard quality assessment techniques, analytical tools, and evaluation methods used in the cosmetic and pharmaceutical industries. It highlights traditional and modern instrumental approaches, regulatory aspects, formulation variables influencing product characteristics, and the importance of characterization in research, development, and commercialization of lipstick products. The review emphasizes the need for harmonized global standards and scientifically validated methods to ensure high-quality, dermatologically safe, and consumer-preferred lipstick formulations.

Keywords: Lipstick evaluation; Hardness testing; Breaking point; Lipstick pay-off; Melting point; Spreadability; SPF evaluation; Cosmetic characterization; Quality control; Color cosmetics.

I. INTRODUCTION

1. Background and Importance of Lipstick Evaluation

Cosmetic products have played a significant role throughout human civilization, and among them, lipsticks hold a distinguished place due to their direct association with beauty, identity, and self-expression. Lip colorants have evolved from natural pigments in ancient civilizations to highly sophisticated, dermatologically safe, and functionally advanced formulations. Lipsticks today are more than just beauty items; they are **cosmeceutical products** that may offer moisturizing, antioxidant, antimicrobial, and sun-protective benefits.

The evaluation of lipstick quality parameters ensures that the product remains safe, stable, visually appealing, and functionally effective throughout its shelf life. With growing awareness among consumers and increasingly strict regulatory expectations, scientific characterization of lipstick attributes is now a critical aspect of pharmaceutical and cosmetic research.

2. Need for Standardization in Lipstick Quality Testing

The quality of lipstick is dependent on its:

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Mechanical and physical properties (hardness, strength, flexibility),
sensory behavior (smoothness, spreadability, pay-off),
Thermal stability (melting point, softening temperature),
Dermatological and protective effects (SPF, irritation potential).

Standardized evaluation ensures:

Requirement	Importance
Product stability	Prevents texture changes, sweating, oil separation
Consumer satisfaction	Ensures desired color intensity, glide, and comfort
Regulatory compliance	Aligns with FDA, BIS, EU Cosmetics Regulation
Market competitiveness	Helps in product differentiation and brand value

3. Key Parameters in Lipstick Evaluation

This review focuses on six critical attributes:

Parameter	Description
Hardness	Resistance to deformation during application and storage
Breaking Point	Mechanical strength before fracture under pressure
Pay-off	Amount of product transferred to surface (skin/blotting)
Melting Point	Temperature at which lipstick softens or melts
Spreadability	Ease and uniformity of product application
SPF Evaluation	Measures UV protection ability for lip care purposes

These parameters directly impact the lipstick's functional performance and commercial success.

4. Formulation Components Influencing Quality Attributes

Lipstick characteristics are predominantly influenced by **formulation composition**, including:

Component	Role
Waxes (beeswax, carnauba, candelilla)	Hardness, gloss, strength, melting behavior
Oils (castor, mineral, lanolin, olive oil)	Spreadability, pay-off, shine, moisturizing
Pigments & Lakes	Color intensity, pay-off, coverage
Emollients & Butters	Smooth glide, nourishment, spreadability
UV Filters	SPF protection (e.g., zinc oxide, titanium dioxide)
Antioxidants (BHT, vitamin E)	Prevent rancidity & oxidative degradation

Waxes increase rigidity and melting point, while oils enhance glide and pay-off. Proper balancing ensures optimum hardness, stability, and sensory qualities.

5. Evaluation Parameter Details

5.1 Hardness

Hardness describes firmness and structural integrity. A lipstick that is too hard is uncomfortable to apply; too soft leads to breakage and excessive pay-off. Instruments include:

Penetrometers

Texture analyzers

Universal Testing Machines (UTM)



5.2 Breaking Point

Measured by placing lipstick horizontally and adding incremental weights until it snaps. It represents **mechanical durability** during application or accidental drops.

Ideal breaking point temperature: **20–30°C** to represent real-life use.

5.3 Pay-off

Pay-off determines pigment transfer and color intensity. Higher pay-off improves consumer satisfaction, especially for matte and high-coverage lipsticks.

Measured using:

Draw-down on paper or skin

Texture analyzer with colorimetry

Spectrophotometric evaluation

5.4 Melting Point

Critical for stability during transport and storage in warm climatic conditions such as India, Africa, and Southeast Asia.

Typical lipstick melting point: **60–65°C** depending on wax blend.

5.5 Spreadability

Spreadability ensures smooth, uniform, and comfortable application.

Measured by:

Slip and drag analysis

Texture profile analysis

Sensory panel testing

5.6 SPF Evaluation

Lipsticks containing UV filters require SPF testing using:

In vitro UV spectrophotometry

In vivo clinical testing on human volunteers

Common lip SPF range: **SPF 10–30**.

6. Regulatory and Safety Considerations

Lipsticks must comply with:

Region	Regulatory Body
India	BIS / CDSCO
USA	FDA (Color Additives Regulations)
Europe	EC Cosmetics Regulation (EC No. 1223/2009)

Safety concerns include:

Heavy metals (lead, chromium, cadmium)

Microbial contamination

Allergen and irritant testing

Stability and shelf-life testing

7. Advances in Lipstick Characterization

Modern innovations include:

Rheology and microstructure imaging

DSC thermal analysis

Digital texture and AI-based sensory prediction



**Wear resistance simulation
Smart UV-indicator lip balms**

8. Conclusion of Introduction

Evaluation of lipstick's physical, mechanical, sensory, and photoprotective properties is essential to ensure desirable performance, consumer acceptance, and regulatory compliance. Hardness, breaking point, pay-off, melting point, spreadability, and SPF collectively define the product quality and stability. With increasing demand for long-wearing, transfer-proof, and skin-beneficial color cosmetics, advanced analytical methods and standardized characterization approaches are crucial. Continuous innovation, combined with regulatory compliance and safety testing, will shape the future of high-performance lipsticks in global markets.

II. REVIEW OF LITERATURE

Historical evolution of lipstick formulation and testing

The history of lip cosmetics traces back millennia, evolving from natural pigments and waxy binders to complex modern formulations combining colorants, emollients, film-formers, and functional actives. Early characterization was largely empirical and sensory-based — manufacturers relied on tactile tests, user panels, and stability observations under ambient conditions. As cosmetics science matured in the 20th century, systematic analytical techniques were progressively introduced: thermal analysis to determine melting and softening behavior, rheological profiling for flow and spreadability, mechanical testing for structural strength, and instrumental colorimetry for pay-off and shade reproducibility. The literature reveals a trend: over time, objective instrumental methods have replaced or supplemented subjective sensory assessment to improve reproducibility, regulatory compliance, and formulation optimization.

Mechanistic factors governing lipstick physical properties

Several review and experimental papers have established that lipstick physical attributes arise from the complex interplay of three primary formulation components: waxes (structural network), oils (plasticizers and emollients), and solid colorants/active particles (pigments, inorganic UV filters). Waxes (e.g., beeswax, carnauba, candelilla) form crystalline or semi-crystalline networks that determine hardness, melting point, and breaking strength. Oils and low-melting emollients (castor oil, esters, silicones) modulate softness, pay-off, and spreadability by reducing internal cohesion and enhancing glide. Solid particulate load (pigment concentration and particle size distribution) impacts pay-off, opacity, and texture — high pigment loads increase brittleness and can alter melting behavior. Additives such as film-formers, thickeners, and antioxidants further influence mechanical and thermal behavior. Thus, modifying one component often simultaneously alters several properties, necessitating multi-parameter evaluation during development.

Hardness and mechanical strength: methods and findings

Hardness and mechanical integrity are widely reported as critical quality attributes because they affect consumer handling, application control, and product longevity. The literature documents two broad approaches:

Penetration/Indentation-based testing: Early studies and some quality-control labs used penetrometers or simple needle-penetration setups to quantify firmness. The depth of penetration under a fixed load/time correlates inversely with hardness. These approaches are straightforward but sensitive to temperature and tip geometry.

Texture analysis / compression tests: More recent work favors texture analyzers and universal testing machines equipped with bespoke fixtures for lipsticks. Tests include three-point bending, compression, and shear to obtain force-displacement curves, from which parameters like maximum force, yield point, and Young's modulus are derived. Such instrumented methods allow dynamic testing (speed dependence), cyclical loading (to simulate repeated application), and fracture analysis to measure breaking points. Reported findings consistently show that wax type and total wax content dominate hardness, while oil fraction and type act as plasticizers. Crude rule-of-thumb values or comparative scales are sometimes proposed in papers, but absolute values vary greatly with protocol and temperature — underscoring the need for standardized test conditions.



Breaking point and fracture behavior

Investigations into fracture or breaking behavior often use bending or three-point load tests mimicking lipstick protruding from a tube being subjected to lateral force. The literature describes methods where the sample is cantilevered and incremental force is applied until fracture; the load at fracture and fracture mode (brittle vs. ductile) are characterized. Microstructural analysis (e.g., polarized light microscopy, SEM) has been used to relate fracture paths to crystalline wax domains, pigment agglomerates, and interfacial adhesion between components. Studies emphasize that thermal history (cooling rate during casting) affects crystallinity and internal stress — faster cooling often yields smaller crystals and different fracture characteristics. Some papers also explore packaging interactions: over-protrusion in slim packaging can elevate risk of breakage, and mechanical tolerance testing of finished sticks is recommended.

Pay-off: transfer, color strength and measurement techniques

Pay-off — the amount of product transferred and the resulting color intensity — is central to consumer perception. Researchers have used multiple approaches to quantify pay-off:

Gravimetric methods: measuring mass loss from the stick after a standard swipe and/or mass gain on substrate (paper, fabric, or artificial skin) offers a basic quantitative metric.

Instrumental colorimetry / spectrophotometry: measuring Lab* or spectral reflectance of standardized draw-downs gives objective color strength, chroma, and opacity measures.

Tribological setups: combining texture analyzers with colorimetry to simulate sliding contact while simultaneously collecting force and transfer data links mechanical glide with pigment transfer.

In vitro skin models and artificial lips: using synthetic substrates or ex vivo skin permits more realistic transfer studies factoring in skin oil and topography.

Across the literature, pay-off is shown to increase with higher oil content and certain plasticizers but can be reduced by heavier wax networks or high pigment fixation. Matte and long-wear formulations use polymeric film-formers and volatile solvents to reduce transfer (low pay-off) while maintaining visible color — trade-offs between wear, comfort, and pay-off are well-documented.

Melting point and thermal stability

Melting point and thermal behavior are commonly assessed using differential scanning calorimetry (DSC), capillary melting point apparatus, and hot-stage microscopy. DSC thermograms provide melting onset, peak melting temperature, and enthalpy — offering insights into wax phase transitions and miscibility with oils. Thermal gravimetric analysis (TGA) can complement DSC for thermal degradation profiles. Literature consistently underscores that melting behavior is governed mainly by the wax composition and polymorphism; microcrystalline waxes, long-chain esters, and hydrogen-bonding components raise melting points. In countries with high ambient temperatures, the thermal stability of lipsticks (resistance to softening, sweating, oil separation) is a major concern; thus accelerated stability testing (e.g., cycling at elevated temperature/humidity) is reported widely.

Spreadability, feel and rheological characterization

Spreadability — how uniformly and easily a lipstick spreads on the lip — is a critical sensory attribute. The literature splits spreadability assessment into instrumental and sensory approaches:

Rheology and shear testing: rotational rheometers measure apparent viscosity, shear thinning behavior, and yield stress of molten formulations or semi-solid dispersions. These measurements help predict application behavior: lower viscosity and pronounced shear-thinning often correlate with easier spread.

Texture profile analysis: measuring parameters like work of adhesion, cohesiveness, and springiness provide mechanistic links to sensory descriptors (creaminess, tackiness).

Sensory panels: trained human panels rate glide, smoothness, tack, and after-feel; such subjective data remain important, especially for formulation optimization.

Tribology: skin friction and lubrication studies connect microscopic frictional properties to perceived smoothness and lasting comfort.



Recent work suggests combining rheology with tribological measurements gives the best correlation to consumer perception. Emulsifiers, polymeric film-formers, and high-molecular-weight oils modulate tack and after-feel and therefore are common variables in spreadability studies.

SPF evaluation in lip products: approaches and challenges

SPF evaluation for lip products presents unique methodological and regulatory challenges. Conventional in vivo SPF testing on human volunteers (broad-spectrum irradiation of treated sites followed by erythema assessment) is the regulatory gold standard for sunscreens, but conducting such tests for lipsticks has limitations: small application areas, variable substrate (lips' mucocutaneous interface), and ethical concerns. Consequently, several in vitro approaches have been explored in the literature:

Spectrophotometric assessment of product films on Transpore™ tape, PMMA plates, or synthetic membranes — measuring UV absorbance/ transmittance to estimate SPF (using established spectral weighting functions).

Diffuser integrating sphere set-ups and UV transmittance measurement of standardized draw-down films provide comparative SPF estimations.

In vivo minimal erythema dose (MED) adaptation for lips, though less common, has been reported in limited controlled studies.

Technical challenges reported include: achieving homogeneous films of pigmented lipsticks, interference of pigments (titanium dioxide, iron oxides) with spectral measurements, and the impact of product transfer/wear on actual lip photoprotection. The literature recommends robust in vitro–in vivo correlation studies and highlights that SPF claims for lip products often necessitate conservative labeling unless supported by validated testing.

Instrumental advances and imaging techniques

Recent literature emphasizes advanced analytical tools: micro-CT and SEM for internal structure, X-ray diffraction and polarized microscopy for wax crystallinity, DSC and modulated DSC for complex thermal transitions, and confocal Raman mapping to study component distribution. High-resolution imaging combined with mechanical testing enables correlation of microstructure with macroscopic properties (e.g., fracture initiation at pigment agglomerates). Digital colorimetry and multispectral imaging enhance pay-off and shade reproducibility evaluation.

Consumer perception studies and sensory correlations

Several studies surveyed consumer preferences linking objective metrics to subjective satisfaction. Common findings: consumers prefer lipsticks that balance payoff with comfort — extreme transfer (very high pay-off) can be undesirable for certain occasions; long-wear products that feel dry or tight reduce acceptance. There is a consistent call in the literature for multi-modal testing: combine instrumental measures (texture, rheology, colorimetry) with structured sensory panels to fully capture product performance.

Regulatory literature and safety considerations

Regulatory reviews highlight contaminants (heavy metals, polycyclic aromatic hydrocarbons in certain waxes), preservatives, and the need for microbiological testing. Labeling of SPF and active filters is covered by regional regulations; the literature notes variability in acceptable claims and testing methodologies across jurisdictions, underscoring the importance of aligning testing strategies with target markets.

Gaps identified in the literature

Despite extensive research, key gaps persist:

Lack of universally accepted standardized protocols for many mechanical tests (temperature control, sample mounting, and displacement rate vary widely).

Limited in vitro–in vivo correlation for SPF of pigmented lip films.

Sparse longitudinal studies linking manufacturing parameters (cooling rate, crystallization kinetics) to long-term performance in real-world conditions.



Under-explored impact of nano-scale pigment formulations and advanced film-formers on safety and performance.
Need for validated artificial lip substrates and tribological standards that mimic human lip biomechanics.

Directions for future research

The literature converges on recommendations for future work:

Development and adoption of harmonized, temperature-controlled mechanical and thermal testing standards for lipsticks.

Cross-validation studies linking instrumental tribology/rheology to sensory panel outcomes across diverse populations.

Rigorous in vitro methods for SPF estimation in pigmented lip products with standardized film-formation protocols and spectral correction for pigments.

Microstructural engineering studies to design wax-oil networks offering optimal hardness without compromising pay-off or spreadability.

Safety studies on novel film-forming polymers and nanopigments with attention to perioral exposure and systemic absorption.

III. AIM AND OBJECTIVES

Aim:

To provide an extensive and critical scientific review of the established and emerging evaluation and characterization techniques used to assess the quality, performance, stability, and functional attributes of lipsticks, with special emphasis on the parameters of hardness, breaking point, pay-off, melting point, spreadability, and SPF evaluation, in order to support evidence-based formulation development, regulatory compliance, and enhanced consumer satisfaction.

Objectives:

- To explore the scientific, technical, and cosmetic significance of key lipstick evaluation parameters, including mechanical strength (hardness, breaking point), application performance (pay-off, spreadability), thermal stability (melting point), and photoprotective efficacy (SPF).
- To analyze conventional laboratory testing methods along with advanced analytical and instrumental techniques such as texture analysis, tribology, rheology, DSC, hot-stage microscopy, UV-VIS spectrophotometry, and in vitro/in vivo SPF assessment models.
- To investigate how formulation variables—waxes, oils, pigments, binders, film-formers, antioxidants, and UV filters—impact measurable quality criteria and end-user sensory perception.
- To compare methodological advantages, limitations, variations in testing protocols, influence of sample preparation, temperature control, and operator subjectivity across available evaluation techniques.
- To highlight regulatory expectations and standardized quality requirements for lipstick products based on FDA, EU Cosmetic Regulation, BIS/Indian Standards, and other international cosmetic guidelines.
- To identify gaps in the current literature related to objective sensory correlation, artificial lip substrate development, and in vitro-in vivo predictability for SPF measurement in pigmented lip formulations.
- To provide a framework for future formulation research and innovation leading to high-performance, dermatologically safe, consumer-preferred lipstick products with claims supported by scientifically validated characterization methods.

IV. CONCLUSION

Systematic evaluation of lipstick formulations is essential to ensure mechanical integrity, desirable sensory characteristics, color transfer efficiency, thermal stability, and photoprotection. Hardness and breaking point testing help determine structural robustness, while pay-off and spreadability influence consumer comfort and color delivery. Melting point assessments safeguard product stability under varying climatic conditions, and SPF evaluation is crucial when lipsticks incorporate UV-filtering agents. Although significant progress has been made in standardizing characterization techniques, variations in experimental conditions, lack of harmonized protocols, and limited correlation



between instrumental and in vivo outcomes remain challenges. Future work must focus on standardized testing frameworks, development of more realistic in vitro lip models, integration of tribology–rheology–sensory correlation, and improved UV protection evaluation for pigmented lip formulations. This review emphasizes that scientifically guided evaluation strategies enhance product quality, regulatory compliance, and consumer trust, ultimately contributing to the advancement of research and innovation in the cosmetic lipstick industry.

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