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Astringency: Molecular Mechanisms, Sensory Profiles, and Mitigation Strategies

A. Jayakalaiarasi[1], Saravanasingh Karan Chand Mohan Singh[2]*, Renga Sundari[3], Shalini Boopathi[4], K. Pavithra[5], M.N. Parandhaman[6], Kanniyakumari. M[7], V. Sathiya[8], C. Vimala[9], C. Devaraj[10]

1. Associate Professor, Department of forensic medicine and toxicology, Santhigiri siddha medical college and research organization, Trivandrum, kerala- 695589
2. Assistant Professor, Department of Maruthuvam, National Institute of Siddha, Ministry of AYUSH, Govt of India, Chennai
3. Professor, Department of Nanju maruthuvam, National Institute of Siddha, Ministry of AYUSH, Govt of India, Chennai
4. Ph.D Scholar, Department of Kuzhanthai Maruthuvam, National Institute of Siddha, Chennai, IND
5. Siddha consultant, Aarudhra siddha and varma clinic, vadapalani, chennai 26
6. Reader, Dept of aruvai thol maruthuvam, JSA Medical College for Siddha and Research Centre, Ulundurpet, Kallakurichi – 606104
7. Associate Professor, Department of Udal Thathuvam, National Institute of Siddha, Ministry of AYUSH, Govt of India, Chennai
8. Associate professor, Department of udal koorugal, JSA siddha medical college & research centre, Pali, ulundhurpet_606104
9. Associate professor, Department of NoiAnuga Vidhi Ozhukkam, Maria Siddha Medical College, Moovattumugam, Attoor, Kanyakumari Dist
10. Associate Professor, Department of Dravya Guna Vijnana, Maria Ayurveda Medical College, Attor, Kanyakumari Dist

***Corresponding Author:**
Dr. Saravanasingh Karan Chand Mohan Singh, M.D (SIDDHA), Ph.D
Assistant professor, Department of Maruthuvam, National Institute of Siddha, Chennai-47
E.Mail: k.saravanasingh@gmail.com

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Abstract

Astringency is a tactile-oral sensation—perceived as drying, roughening, and puckering—that emerges when dietary polyphenols (tannins, flavonoids) complex with salivary proline-rich proteins, depleting lubrication and increasing mucosal friction. Unlike canonical tastes, astringency is mediated mainly by trigeminal mechanoreceptors rather than taste GPCRs and is not suppressed by sweetness. The same molecular features that drive this aversive mouth-feel underlie a broad spectrum of bioactivities, including antioxidant, anti-inflammatory, antimicrobial, antiviral, cardioprotective, and chemopreventive effects. This review integrates current knowledge on: (i) the chemistry of hydrolysable and condensed tannins and their

interactions with saliva; (ii) physiological transduction pathways involving epithelial sodium and acid-sensing ion channels; (iii) the diversity of astringent food matrices and the sensory descriptors they evoke; (iv) pharmacological outcomes ranging from NF-κB inhibition to modulation of digestive enzymes; (v) analytical and tribological methods for quantifying astringency; and (vi) emerging mitigation strategies such as polysaccharide viscosity engineering, inclusion complexes, enzymatic polymerisation, encapsulation technologies, and pharmaceutical taste-masking. Traditional Chinese Medicine perspectives and inter-individual variability linked to salivary protein genetics are also discussed. Finally, research frontiers—high-resolution tannin–protein structures, machine-learning prediction of astringency, green extraction processes, microbiome-derived metabolites, and biomimetic oral lubricants—are highlighted. Understanding and manipulating astringency at the molecular level will enable the development of foods, beverages, and therapeutics that retain the health benefits of polyphenols while delivering superior sensory acceptance.

Keywords: Siddha medicine, Astringency; tannins; polyphenols; proline-rich proteins; oral tribology; antioxidant activity; taste masking; food texture; sensory science; Traditional Chinese Medicine

1 Introduction

Astringency is the drying, roughening, and puckering mouth-feel elicited by many plant-derived foods and beverages such as red wine, green tea, unripe persimmon, dark chocolate, and certain medicinal decoctions. Although lay people frequently describe astringency as a "taste," psychophysical and neurophysiological studies show that it is **not** mediated by taste GPCRs. Instead, it emerges from physicochemical interactions between polyphenolic compounds—chiefly tannins—and salivary macromolecules that reduce oral lubrication and enhance friction on the oral mucosa (Gawel 2006; Golebiowski et al. 2011). Astringent molecules possess a rich pharmacological portfolio: antioxidant, anti-inflammatory, antimicrobial, antiviral, cardioprotective and anticarcinogenic activities have all been documented (He et al. 2015; Han et al. 2022). Thus, the same structural features that create an unpleasant tactile sensation often confer valuable bioactivity.

Because modern consumers prefer smooth textures, the agri-food and pharmaceutical sectors devote considerable effort to *attenuating* astringency while preserving these health benefits. This review synthesises current knowledge on (i) the chemistry and oral mechanisms of astringency, (ii) its pharmacological ramifications, (iii) analytical and sensory assessment techniques, and (iv) emerging mitigation strategies, with emphasis on plant-based systems.

2 Physicochemical Basis of Astringency

2.1 Key molecular actors

1. **Hydrolysable tannins** – gallic or ellagic acid esters of glucose (e.g., tannic acid, punicalagin).
2. **Condensed tannins (proanthocyanidins)** – oligomers of flavan-3-ol units (catechin, epicatechin).
3. **Low-molecular-weight polyphenols** – flavonols, flavanones, anthocyanins.
4. **Metal salts & multivalent cations** – Al^{3+}, Fe^{3+}, Zn^{2+} produce "chemical" astringency.

5. **Organic acids** – oxalic, malic and citric acids can augment astringent mouth-feel at low pH.

2.2 Interaction with saliva

Saliva contains **proline-rich proteins (PRPs)**, **histatins**, **mucins** and **statherin** that normally lubricate the oral epithelium. Polyphenols form reversible and irreversible complexes with PRPs through hydrogen bonding, hydrophobic stacking, and metal bridging (Baxter et al. 1997). When the complexes reach a critical aggregation size they precipitate, depleting lubricants and increasing mucosal friction as measured by oral tribology (Laguna et al. 2017).

2.3 Peripheral sensory transduction

De-lubrication exposes mechanoreceptors and activates trigeminal free nerve endings (V–cranial nerve), generating dryness and puckering. Recent work implicates epithelial sodium channels (ENaC) and acid-sensing ion channels (ASIC) in transducing the rough tactile input (Brockhoff et al. 2021). Notably, sweetness, unlike bitterness, **does not suppress** astringency, underscoring its independence from taste bud signalling (Gawel 2006).

3 Classification of Astringent Foods & Beverages

Matrix	Dominant polyphenols	Typical astringency descriptors
Red wine	Condensed tannins + anthocyanin-tannin adducts	Dry, coarse, puckering
Green tea	Gallate-type catechins (EGCG)	Puckering, puckish bitterness
Cocoa/chocolate	B-type procyanidins	Chalky, drying
Persimmon (unripe)	Soluble persimmon tannin (SPT)	Intense mouth-draw
Pomegranate	Ellagitannins	Sour-dry
Cranberry	A-type proanthocyanidins	Sharp, drying
Beer (dry-hopped)	Hop polyphenols	Rough, woody

The magnitude and *quality* of astringency vary with tannin size, degree of galloylation, and matrix factors such as pH, ethanol, sugar, and viscosity (Soares et al. 2019).

4 Pharmacological Activities of Astringent Compounds

4.1 Antioxidant and chemopreventive effects

Polyphenols donate electrons or hydrogen atoms to neutralise reactive oxygen species (ROS), up-regulate Nrf2-dependent antioxidant genes, and inhibit lipid peroxidation (Scalbert et al. 2005). Long-term tea and cocoa consumption correlates with reduced incidence of cardiovascular disease and certain cancers.

4.2 Anti-inflammatory actions

Tannic acid, persimmon tannin and EGCG suppress NF-κB activation, down-regulate pro-inflammatory cytokines (IL-6, TNF-α) and inhibit COX-2 (Choi et al. 2019; He et al. 2015).

4.3 Antibacterial and antiviral properties

Condensed tannins complex bacterial cell-wall proteins and viral envelope proteins, impairing

adhesion and replication. EGCG shows micromolar inhibition of SARS-CoV-2 3CLpro in vitro (Jang et al. 2021).

4.4 Metabolic modulation

Tea and persimmon tannins inhibit α-amylase, α-glucosidase and lipase, moderating post-prandial glycaemia and lipidaemia (Ikarashi et al. 2020).

4.5 Other bioactivities

- Chelation of heavy metals.
- Photoprotective and dermatological uses.
- Gastrointestinal astringents in traditional medicine for diarrhoea.

5 Analytical & Sensory Assessment

5.1 Sensory protocols

1. **Time–Intensity (TI)** – records onset, crescendo, and decay.
2. **Descriptive Analysis (DA/QDA)** – trained panels produce attribute profiles.
3. **ASTM E253–20** astringency standard.

5.2 Instrumental correlates

- **Protein precipitation assays** (BSA, α-amylase).
- **Turbidimetry and nephelometry** – kinetics of aggregate formation.
- **Friction coefficient (μ) curves** with a soft tribopair simulate tongue–palate sliding (Laguna et al. 2017).
- **Quartz-crystal microbalance with dissipation (QCM-D)** – real-time mass and viscoelastic monitoring of salivary protein layers.
- **HPLC-DAD/ESI-MS** for detailed polyphenol profiling.

6 Modulation and Masking Strategies

6.1 Matrix engineering

1. **Polysaccharides** – High-molecular-weight gums (xanthan, pectin) create viscosity and steric hindrance, reducing tannin–protein collisions.
2. **Cyclodextrins & cyclofructans** – inclusion complexes sequester small gallates (Nishioka et al. 2003).
3. **Milk proteins** – β-casein binds tea catechins, dulling astringency in "milk tea."
4. **Grapefruit cold-press oil** – terpene-rich nanoemulsion coats oral surfaces and suppresses friction (Kenji 2011).

6.2 Chemical modification

- **Acetaldehyde treatment** polymerises persimmon tannin, rendering it insoluble (hiratanenashi de-astringency).
- **Enzymatic oxidation** by laccase converts catechins to theaflavins, altering mouth-feel in black tea.

6.3 Encapsulation & delivery systems

Nano-liposomes, spray-dried microcapsules, and Pickering emulsions can spatially control polyphenol release, balancing bioactivity and sensory acceptance (Tavernier et al. 2020).

6.4 Pharmaceutical taste masking

Ion-exchange resins, film-coated microparticles and pH-triggered capsules hide the astringency of herbal extracts in oral dosage forms, improving compliance in paediatric and geriatric

populations (Han et al. 2022).

7 Traditional Chinese Medicine (TCM) Perspective

"Astringent" (涩 sè) is one of the seven true TCM tastes, linked to the energetic function of *binding and consolidating*. Herbs such as **Schisandra chinensis** (**五味子**), **Cornus officinalis** (**山茱萸**) and **Diospyros kaki calyx** (**柿蒂**) are prescribed to curb diarrhoea, sweating and seminal emission. Modern phytochemistry attributes these effects to ellagitannins and lignans that tighten mucosal junctions and reduce secretions. Balancing the strong涩 taste necessitates co-administration of sweet or spicy herbs—an empirical masking strategy practiced for millennia (Jun-zhi et al. 2007).

8 Inter-Individual Variability

Genetic polymorphisms in **PRH1/PRH2** (acidic PRP genes) and variations in salivary flow rate influence perceived astringency (Horne et al. 2020). Ageing reduces saliva production, intensifying dryness and altering acceptance thresholds, a consideration for product design targeting elderly consumers.

9 Emerging Research Frontiers

1. **High-resolution structures** of tannin–PRP complexes (cryo-EM, NMR) to enable *in silico* prediction of astringency potency.
2. **Machine-learning models** linking molecular fingerprints to sensory output for accelerated ingredient screening.
3. **Sustainable extraction** – green solvents and biorefinery cascades valorise tannin-rich agro-wastes.
4. **Gut microbiome interactions** – microbial catabolism of tannins produces urolithins and phenyl-γ-valerolactones with systemic health effects (Selma et al. 2009).
5. **Edible tribofilms** – biomimetic lubricating layers (e.g., mucin-inspired glycoproteins) applied to beverage surfaces to counteract dryness.

10 Conclusion

Astringency is a unique multimodal sensation born from the intersection of **polyphenol chemistry and oral biophysics**. While often viewed as an undesirable attribute, the same molecules responsible for dryness furnish a treasure trove of **pharmacological benefits**, from antioxidation to antiviral defence. Advances in tribology, proteomics, encapsulation, and computational modelling are enabling **precision control** over astringency, promising products that marry health and hedonics. Future work must integrate sensory science with nutrition, genetics and microbiomics to fully harness—and, when desirable, tame—the power of astringent phytochemicals.

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