

Formulation Performance of a Microencapsulated Eucalyptus-Herbal Sugar-Free Hard Candy and Its Relevance to Pharyngeal Comfort

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ABSTRACT

Objective: A hard candy remains in contact with the oral cavity for several minutes, so volatile retention, botanical taste and matrix stability all affect the finished product. We evaluated a sugar-free NVTIA hard candy containing monk fruit, *Platycodon grandiflorus*, lily bulb and low-glycyrrhizic-acid licorice extracts together with microencapsulated eucalyptus oil and menthol. **Method:** The optimized 2.50-g candy used an isomalt-maltitol-erythritol matrix. Botanical extracts were added at 108°C, followed by eucalyptus oil microcapsules and menthol at 92°C. The finished candy contained 2.35% moisture and had a mean unit mass of 2.50 g. In the 10-member experienced sensory panel, eight panelists rated eucalyptus-flavor uniformity as excellent, seven rated herbal bitterness as excellent (indicating slight bitterness), and eight rated overall acceptability as excellent. **Results:** Relative retention of 1,8-cineole was 82.1%. Replacing the microcapsule with liquid eucalyptus oil reduced 1,8-cineole retention to 64.5% and produced less uniform flavor. Removing lily preserved cineole retention but worsened bitterness and acceptability. Randomized human studies have reported reduced postoperative throat discomfort with topical licorice in several settings, including a licorice-lozenge study. Trials of a licorice-*Platycodon* combination for acute upper-respiratory-tract-infection sore throat found similar short-term improvement in active and placebo groups. **Novelty:** The formulation results define the sensory and volatile-retention performance of the complete candy and identify direct symptom and sensory endpoints for formulation-specific pharyngeal-comfort studies.

INTRODUCTION

Throat discomfort occurs in several settings, including transient upper-airway irritation, respiratory infection and airway instrumentation. For a product that dissolves slowly in the mouth, the dosage form determines how evenly volatile ingredients are delivered and how much bitterness is perceived during use. These issues become especially relevant when eucalyptus oil, menthol and several botanical extracts are combined in a sugar-free hard-candy matrix.

The NVTIA formulation contains four botanical extracts: monk fruit, *Platycodon grandiflorus*, lily bulb and low-glycyrrhizic-acid licorice. Eucalyptus oil is supplied as a spray-dried microcapsule rather than as free liquid oil, and menthol is included in the same cooling-aromatic fraction. The botanical and volatile fractions are introduced at different cooling stages. We used this formulation architecture to examine whether a stable, uniform sensory profile could be maintained while preserving a composition that is relevant to published human work on throat comfort.

Randomized human work on topical licorice has used both gargles and lozenges in postoperative throat discomfort [1]–[4]. *Platycodon* has also been studied with licorice as Kikyo-to in acute URTI-associated sore throat [5], [6], and a more recent trial examined

licorice gargling after oropharyngeal surgery [7]. The same candy contains menthol and eucalyptus-derived 1,8-cineole, so a second line of evidence is relevant: menthol challenge studies have measured cough threshold and perceived airway patency [8]–[11], while oral cineole trials have reported respiratory outcomes in bronchitis, asthma and COPD [12]–[15]. These studies use different routes, doses and symptom models; they are therefore treated as physiological context rather than as direct efficacy evidence for the finished candy.

We first characterized the optimized NVTIA hard candy by measuring volatile-marker retention, sensory uniformity, bitterness and overall acceptability. We then reviewed randomized studies of licorice and licorice-Platycodon preparations to place the formulation findings in a human clinical context and to identify endpoints suitable for direct evaluation of the complete candy.

MATERIALS AND METHODS

Formulation composition

Table 1. Optimized composition of the 2.50-g sugar-free herbal hard candy. Parts are expressed per 100 parts formulation.

Component	Optimized level	Functional role
Isomalt	75.685 parts	Sugar-alcohol matrix
Maltitol syrup (dry basis)	20.000 parts	Sugar-alcohol matrix
Erythritol	2.500 parts	Sugar-alcohol matrix
Monk fruit extract	0.400 part; 10.00 mg/piece	Mogroside-containing botanical extract
Platycodon grandiflorus water extract	0.280 part; 7.00 mg/piece	Herbal component
Lily bulb water extract	0.650 part; 16.25 mg/piece	Herbal component
Low-glycyrrhizic-acid licorice extract	0.080 part; 2.00 mg/piece	Herbal component
Eucalyptus oil microcapsule powder	0.220 part; 5.50 mg/piece	Volatile-flavor carrier
Menthol	0.035 part; 0.875 mg/piece	Cooling sensory component
Citric acid	0.120 part	Acidulant
Sodium citrate	0.030 part	Acid-base regulator

Manufacturing and experimental evaluation

The formulation was prepared on a 100-parts-by-weight basis. Isomalt, maltitol syrup calculated on a dry-matter basis and erythritol formed the sugar-alcohol matrix. The botanical fraction consisted of monk fruit extract, Platycodon grandiflorus water extract, lily bulb water extract and low-glycyrrhizic-acid licorice extract. Eucalyptus oil

microcapsule powder and menthol were used as the principal cooling-aromatic components. No phospholipid emulsifier was used.

Maltodextrin and gum arabic were dissolved in purified water at 50°C for microcapsule preparation. Eucalyptus oil was then added, and the mixture was shear-emulsified at 8000 r/min for 10 min. The emulsion was homogenized twice at 25 MPa and spray-dried at inlet and outlet temperatures of 165°C and 82°C, respectively. The candy matrix was vacuum-cooked at 148°C and -0.085 MPa until the solid content reached 97%. At 108°C, the botanical extracts, citric acid and sodium citrate were added and mixed at 45 r/min for 4 min. Eucalyptus oil microcapsule powder and menthol were added after further cooling to 92°C and mixed at 30 r/min for 2 min. The mass was cast into molds preheated to 40°C, cooled at 18°C for 12 min, demolded and hermetically packaged.

Moisture was measured by direct drying. Unit mass was determined in 20 randomly selected candies. Relative retention of 1,8-cineole was measured by gas chromatography using an external-standard approach. A blinded three-grade sensory assessment was completed by 10 individuals with food-sensory-evaluation experience. Eucalyptus-flavor uniformity and overall acceptability were treated as positive indicators. For herbal bitterness, an 'excellent' rating represented slight bitterness and a 'poor' rating represented obvious bitterness.

Three comparator formulations were examined. One used an equivalent amount of liquid eucalyptus oil instead of the microcapsule. In a second condition, the eucalyptus oil microcapsules and menthol were added at 128°C rather than after staged cooling. In the third, lily bulb extract was removed and replaced with an equal amount of isomalt. These comparisons addressed microencapsulation, thermal timing and botanical balance separately.

PubMed/MEDLINE and primary journal records were searched through 18 August 2026 using combinations of licorice, Glycyrrhiza, Platycodon, Kikyo-to, sore throat, pharyngeal pain, gargle, lozenge, randomized, menthol, cough threshold, eucalyptus, eucalyptol, 1,8-cineole, bronchitis, asthma, COPD and clinical trial. Human controlled trials were prioritized when they addressed topical throat exposure, licorice-Platycodon use, menthol-mediated cough or airway sensation, or oral cineole respiratory outcomes. Ingredient-level clinical findings were used only to frame endpoints and physiological plausibility for the composite product; claims about the complete candy remained anchored to the formulation experiments described above.

RESULTS

Physical and sensory performance

Mean moisture content was 2.35%, and mean unit mass was 2.50 g. Across the 20 sampled candies, mass deviation remained within ± 0.03 g. The candy bodies were complete and smooth on visual inspection, with no cracking, particle adhesion or obvious local agglomeration of botanical extracts or eucalyptus oil microcapsule powder.

Relative 1,8-cineole retention in the optimized formulation was 82.1%. Eight of the 10 panelists rated eucalyptus-flavor uniformity as excellent and two as good. Herbal bitterness received seven excellent and three good ratings, corresponding mainly to slight bitterness. Overall acceptability was rated excellent by eight panelists and good by two.

Comparator analysis

Replacing the microcapsule with liquid eucalyptus oil reduced relative 1,8-cineole retention to 64.5%. Only one panelist rated flavor uniformity as excellent, and four rated it poor. Overall acceptability was rated excellent by two panelists, good by five and poor by three. Local aggregation of liquid oil was also visible in the candy matrix.

Adding the microcapsule powder and menthol at 128°C gave 68.2% relative 1,8-cineole retention even though the formulation composition was unchanged. When lily bulb extract was removed, cineole retention remained at 81.7% and eucalyptus-flavor uniformity remained good. Sensory balance changed, however: six of ten panelists rated herbal bitterness as poor, and only one rated overall acceptability as excellent. Lily removal therefore affected taste more than volatile retention in this comparison.

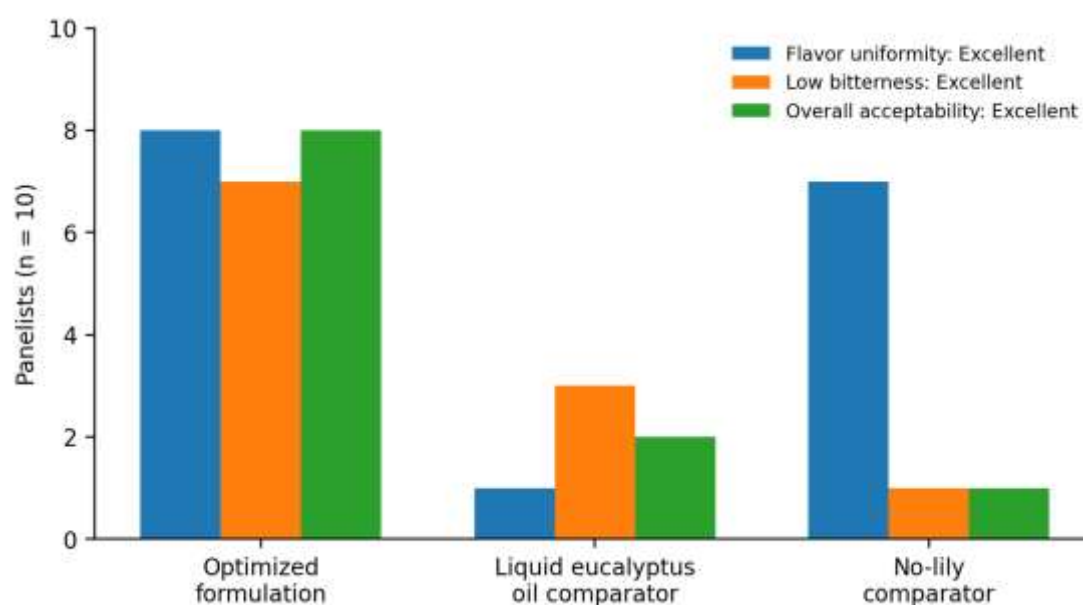


Figure 1. Descriptive sensory ratings for the optimized formulation and two key comparators. “Excellent” for bitterness denotes slight bitterness. No inferential statistics were specified for the 10-member sensory panel.

Human clinical evidence relevant to throat comfort

Agarwal et al. [1] reported lower incidence and severity of postoperative sore throat at most assessed time points after a 0.5 g licorice gargle. Ruetzler et al. [2] studied 236 patients undergoing thoracic surgery; postoperative sore-throat incidence was lower with licorice than with sugar-water at 30 min, 90 min and 4 h. In smokers given licorice lozenges before anesthesia, Gupta et al. [3] reported postextubation cough in 24% of the licorice group and 52% of the sugar-candy group, with more favorable sore-throat grades at later time points.

Kikyo-to, a Platycodon-licorice combination, was examined in two randomized trials of acute URTI-associated sore throat [5], [6]. Both active and placebo groups improved over the short assessment period, and the between-group differences at 10 or 30 min were not statistically significant. In a 2024 randomized trial after oropharyngeal surgery, licorice gargling produced pain and opioid-use outcomes similar to the sugar comparator [7]. The contrast between these studies shows why symptom origin, severity, dose, contact pattern and assessment timing need to be specified in formulation-specific trials.

Table 2. Primary human studies used to define the clinical context for pharyngeal-comfort evaluation.

Study	Design	Intervention	Endpoint	Key finding
Agarwal et al. [1]	Randomized, single-blind; n=40	0.5 g licorice gargle before intubation	Postoperative sore throat (POST)	Lower incidence/severity of POST at most time points; postextubation cough also reduced.
Ruetzler et al. [2]	Randomized, double-blind; n=236	0.5 g licorice vs sugar-water gargle	POST after double-lumen intubation	POST incidence was lower with licorice at 30 min, 90 min and 4 h.
Gupta et al. [3]	Randomized; n=100 smokers	Licorice lozenge vs sugar candy	Postextubation cough and sore throat	Cough incidence 24% vs 52%; sore-throat grades favored licorice at 12 and 24 h.
Ishimaru et al. [5]	Double-blind RCT; n=70	2.5 g Kikyo-to (licorice + Platycodon) vs placebo	URTI-associated sore throat at 10 min	Both groups improved; between-group difference was not statistically significant.
Ishimaru et al. [6]	Multicenter double-blind RCT; n=68 analyzed	2.5 g Kikyo-to vs placebo	URTI-associated sore throat at 30 min	Similar short-term VAS changes in active and placebo groups.

Study	Design	Intervention	Endpoint	Key finding
Windpassinger et al. [7]	Randomized, double-blind; n=126	1 g licorice gargle vs sugar placebo	Pain after oropharyngeal surgery	Pain and morphine outcomes were similar, indicating indication- and severity-dependent response patterns.

Menthol and cineole add a different, but complementary, human context. In controlled cough-challenge work, menthol reduced citric-acid- or capsaicin-evoked cough sensitivity in several adult studies [8]–[10], while a pediatric crossover study found a clearer effect on perceived nasal patency than on cough counts [11]. Oral cineole has also been tested at pharmacological doses in acute bronchitis, asthma and COPD [12]–[15]. Those exposures are not equivalent to a hard candy, but they help identify cough urge, cooling sensation and respiratory comfort as measurable outcomes alongside throat-discomfort ratings.

Discussion

Microencapsulation and the timing of volatile addition had a clear effect on the finished candy. Relative 1,8-cineole retention was higher in the optimized product than after direct liquid-oil addition or addition of the microcapsule fraction at high temperature. The optimized candies also avoided the local oil aggregation seen with liquid eucalyptus oil. For a slowly dissolving oral product, these processing differences matter because each unit should deliver a similar cooling-aromatic profile during use.

The lily comparison produced a different pattern. Removing lily left 1,8-cineole retention essentially unchanged, but bitterness increased and overall acceptability fell. This separates volatile preservation from botanical taste balance within the tested formulation. Eucalyptus microencapsulation and low-temperature incorporation mainly affected volatile retention and flavor uniformity; lily was associated with the more acceptable bitterness profile observed in the complete candy.

The clinical studies do not point to a single response across all throat-discomfort models. Postoperative intubation trials tested topical licorice close to the site of pharyngeal irritation and reported favorable outcomes in several settings [1]–[4]. The licorice-lozenge trial is particularly relevant to an orally retained solid dosage form because the exposure format resembles a candy-like product [3]. The two Kikyo-to studies, however, found similar short-term improvement in active and placebo groups for acute URTI-associated sore throat, with assessments at 10 or 30 min [5], [6]. The 2024 oropharyngeal-surgery trial likewise found similar pain and opioid-use outcomes with

licorice and sugar gargles [7]. Different symptom models and assessment times therefore produce different clinical signals.

The complete NVTIA candy differs from the products used in those trials. It combines low-glycyrrhizic-acid licorice, a defined Platycodon-lily-herbal ratio, microencapsulated eucalyptus oil, menthol and a polyol hard-candy matrix. The topical-licorice literature [1]–[7] and the menthol/cineole studies [8]–[15] point to partly overlapping but not identical outcome domains. For that reason, a randomized product study would be more informative if it records throat scratchiness or irritation, swallowing discomfort, perceived cooling, cough urge, onset and duration of comfort, and acceptability rather than compressing the response into a single pain score.

Palatability is also part of formulation performance for a product that remains in the mouth. Sensory uniformity affects consistency of exposure across participants, and excessive bitterness can change willingness to continue oral contact with the candy. In future human work, sensory ratings can therefore be recorded alongside throat-symptom outcomes rather than treated only as a product-development measure.

Study Considerations and Future Directions

The formulation experiments directly characterized volatile retention, sensory consistency, bitterness control and physical appearance of the finished candy. The clinical literature contributes two distinct layers: topical licorice/licorice-Platycodon studies for throat-discomfort endpoints [1]–[7], and menthol/cineole studies for cough, cooling and broader respiratory physiology [8]–[15]. Keeping those layers separate from the product data helps avoid attributing ingredient-level findings to the complete candy while still giving a practical basis for endpoint selection.

A product-specific study could use standardized throat-discomfort scales together with cough-urge ratings, time to perceived relief, salivary or mucosal-contact variables and repeated dosing under defined use conditions. Separate enrollment by symptom model, such as transient irritative throat discomfort and acute infectious sore throat, would allow the response to be examined in more uniform clinical settings.

CONCLUSION

Fundamental Finding: The optimized microencapsulated eucalyptus-herbal sugar-free hard candy achieved 82.1% relative 1,8-cineole retention with favorable ratings for eucalyptus-flavor uniformity, herbal bitterness and overall acceptability. Comparator testing separated the roles of microencapsulation, staged cooling and lily-mediated taste balance. **Implication:** The formulation profile supports direct human evaluation of the complete NVTIA candy using pharyngeal-comfort and sensory endpoints matched to the way the product is used. **Limitation:** Randomized human studies report favorable topical-licorice findings in several postoperative throat-irritation settings, while other throat-discomfort models show more variable short-term responses. **Future Research:** The formulation profile supports direct human evaluation of the complete NVTIA candy

using pharyngeal-comfort and sensory endpoints matched to the way the product is used.

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