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Research Article

From Flower to Anthocyanin-Powered Optical Tooth Whitening: A Peroxide-Free Optical Tooth-Whitening Approach Using Butterfly Pea Flower (*Clitoria ternatea*) Extract

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ABSTRACT

Background: Tooth discolouration is a widespread cosmetic concern, and the global cosmetic oral care market is projected to reach USD 8 billion by 2026. Conventional whitening systems rely on hydrogen peroxide or carbamide peroxide, which are associated with tooth sensitivity, enamel erosion, and gingival irritation on prolonged use. Optical colour correction, in which a purple pigment neutralises yellow tones on the tooth surface through complementary-colour theory, has emerged as a non-invasive alternative, but marketed purple whitening products predominantly use synthetic colourants such as blue covarine or PAP dyes. Aim: To formulate and evaluate a herbal purple toothpaste and a dissolving whitening strip using anthocyanin (ternatin) extract from butterfly pea flower (Clitoria ternatea) as a natural, peroxide-free, edible-grade optical colour-correcting agent. Methodology: Anthocyanin extract was obtained by aqueous extraction of sun-dried, powdered butterfly pea flowers (80 °C, 1 hour), followed by filtration and concentration. Dissolving whitening strips were prepared by solvent-casting a film-forming solution of HPMC E15 and CMC-Na, plasticised with glycerine, sorbitol and PEG 400, incorporating the anthocyanin extract, and drying to a flexible film. A purple herbal toothpaste was prepared by dispersing calcium carbonate and tamarind seed powder (abrasives) with sodium lauryl sulfate (foaming agent) and the anthocyanin extract in a glycerine–sorbitol–CMC-Na gel base, flavoured with peppermint oil. Both products were evaluated for organoleptic properties, pH, and short-term physical stability; the strips were additionally assessed for thickness, folding endurance and disintegration time, and the toothpaste for foaming ability and spreadability. Results: The whitening strips exhibited a uniform violet-blue colour, mean weight of 0.148 ± 0.012 g (CV 8.1%), a mean folding endurance of 289.8 folds,

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and a mean disintegration time of 11 minutes (range 10–12 minutes) in artificial saliva. The purple toothpaste showed satisfactory organoleptic properties, 75% foam retention at 1 minute, progressive spreadability with applied load, and physical stability (colour, texture, pH) over a 30-day observation period, with only slight colour fading noted from Day 15, attributable to the pH- and light-sensitivity of anthocyanins.

INTRODUCTION

1.1 Tooth discolouration: prevalence and burden

Tooth discolouration is a common aesthetic concern arising from extrinsic causes (dietary chromogens such as tea and coffee, tobacco use, poor oral hygiene, and plaque or calculus accumulation), intrinsic causes (dental fluorosis, tetracycline staining, trauma, and genetic factors), and other contributing factors such as ageing, medication use, and environmental exposure.[1,3] Dental problems are reported to affect nearly 90% of the Indian population, with an estimated 14% of individuals at heightened risk of noticeable tooth discolouration due to a combination of these intrinsic and extrinsic factors. A rising influence of social media and professional presentation norms has further increased demand for aesthetic dental treatments, and the global cosmetic oral care market is projected to reach USD 8 billion by 2026.

1.2 Limitations of existing whitening methods

Conventional tooth whitening relies principally on peroxide-based bleaching agents (hydrogen peroxide and carbamide peroxide) which oxidise chromogenic molecules within the tooth structure.[1] Although effective, these agents are associated with tooth sensitivity, enamel erosion, gingival irritation, higher cost, and a risk of over-bleaching with prolonged or improper use.[1,3] These drawbacks have motivated the search for safer, plant-derived, peroxide-free alternatives that can deliver a whitening benefit without chemically altering tooth structure.[1,18].

1.3 Purple colour-correction technology

Optical colour correction offers a non-invasive alternative to chemical bleaching.[2,18] According to colour theory, complementary colours positioned opposite one another on the colour wheel neutralise each other when combined.[2,5] Because yellow and purple are complementary, the application of a purple pigment to yellow-stained teeth visually cancels the yellow tone, producing an immediate, though optical rather than structural, whitening effect, a principle already exploited commercially in purple shampoos used to counteract yellow discolouration in light-coloured hair.[2,5,18] Marketed purple whitening formats include toothpaste, serum, foam, and dissolving strips, which differ in contact time, ease of application, and durability of effect (Table 1).[2,12] Among these, strips provide the longest direct contact time and the most sustained colour-correction effect, whereas toothpaste offers convenience for routine daily use.[6,12]

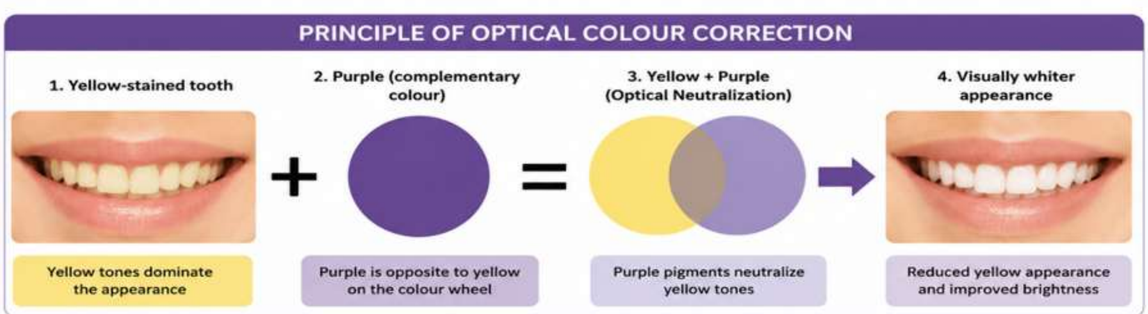

Figure 1. Principle of optical colour correction using complementary colour theory

Table 1. Comparative overview of marketed purple whitening formulation types

Formulation	Advantages	Disadvantages	Remark
Purple toothpaste	Easy daily use	Temporary effect; low contact time	Routine maintenance product
Purple serum	Quick, instant cosmetic effect	Short duration; uneven application possible	Suited to quick results, not lasting effect
Purple foam	Spreads easily; cleans while whitening	Low retention time; less effective whitening	Supportive product only
Purple whitening strip	Direct contact; longer duration; better whitening	Slightly higher cost; requires correct placement	Selected formulation for this study, better adhesion and effectiveness

1.4 Tooth-whitening strips and the role of anthocyanin

Dissolving/oral whitening strips are thin polymeric films designed for direct, sustained contact with the tooth surface.[6,12] Anthocyanins are water-soluble flavonoid pigments responsible for red, purple and blue colouration in numerous fruits, flowers and vegetables (e.g., blueberry, purple cabbage, blackberry, grape, black rice, hibiscus, jamun and butterfly pea) and possess antioxidant, anti-inflammatory and antimicrobial activity in addition to their colouring function.[7,9,20] Among natural anthocyanin sources, butterfly pea flower (Clitoria ternatea) yields a comparatively true blue-violet pigment (through its principal ternatin anthocyanins) rather than the red-leaning shades typical of berry-derived anthocyanins, which makes it more suited to neutralising yellow tones, produces a lower staining tendency on surrounding tissue, and is compatible with common film-forming and toothpaste excipients (HPMC, CMC, glycerine).[7,11,13,20]

1.5 Need for the study and research gap

- Conventional whitening products remain reliant on peroxide-based agents with well-documented sensitivity and enamel-safety concerns.
- Butterfly pea flower is a well-characterised Ayurvedic plant with documented antioxidant activity and pH-dependent colour behaviour, yet it remains largely unexplored as the pigment source in oral film and toothpaste formulations for cosmetic whitening since most marketed purple whitening products instead use synthetic colourants such as blue covarine or PAP dyes, which are not edible-grade.
- There is a clear need for an affordable, natural, edible-grade, peroxide-free purple whitening system suited to the Indian consumer base and regulatory context.

This represents a research gap that the present study addresses by using a fully edible, GRAS-recognised, Ayurvedic-origin anthocyanin source, rather than a synthetic dye as the active optical colour-correcting agent in both a toothpaste and a dissolving strip format.

1.6 Aim and objectives

Aim: To formulate and evaluate herbal purple toothpaste and dissolving whitening strips using butterfly pea flower (Clitoria ternatea) anthocyanin extract as a natural optical colour-correcting agent for cosmetic teeth whitening a safe, peroxide-free, enamel-friendly alternative to conventional chemical whitening products.

Objectives:

- To prepare a herbal purple whitening formulation using anthocyanin as the active natural pigment.
- To apply colour-theory principles for reducing the visual yellow appearance of teeth.
- To assess whitening effectiveness on stained tooth models or enamel surfaces.
- To evaluate physicochemical parameters such as pH, appearance, colour, thickness, and stability.
- To develop a safer, herbal, and cost-effective whitening product for cosmetic oral care.

2. LITERATURE REVIEW

Table 2. Literature Review

Author (Year)	Topic	Key finding
Joiner (2006)	The bleaching of teeth: a review	Reviewed peroxide-based bleaching mechanisms and introduced colour-theory considerations in tooth whitening.
Joiner et al. (2008)	Optical tooth whitening	Explored mechanisms and effectiveness of optical (non-bleaching) tooth-whitening techniques.
Watts & Addy (2001)	Tooth discolouration and staining: a review	Characterised extrinsic and intrinsic causes of tooth staining.
Ten Bosch & Coops (1995)	Tooth colour and reflectance	Related tooth colour and whiteness perception to light scattering and absorption.
Kulkarni et al. (2010)	Polymers for oral fast-dissolving strips	Reviewed film-forming polymers suited to oral strip formulations.
Nikijuluw (2013)	Colour characteristics of butterfly pea anthocyanin extracts	Reported that the ternatin A1 structure produces red at pH 1–2, purple-to-blue at pH 3–7, and yellow-green at pH 8–14.
Jeyaraj et al. (2021)	Clitoria ternatea: phytochemistry and pharmacology	Detailed extraction procedures and phytochemical profile of butterfly pea.
Aspinall et al. (2021)	Role of abrasives / oral care formulation challenges	Identified calcium carbonate (Mohs hardness 3) as an abrasive that removes plaque without eroding enamel (Mohs hardness ~5).
Enaru et al. (2021)	Anthocyanins: factors affecting stability and degradation	Reviewed pH-, light-, temperature- and oxygen-dependent degradation of anthocyanins.
Arora et al. (2019)	HPMC/CMC buccal films	Characterised HPMC/CMC-based oral films for enhanced solubility and delivery.
Parhi (2017)	Oral film technology: a review	Reviewed advances and applications of oral film technology.
Dewangan et al. (2024)	Toothpaste formulation for sensitivity	Identified sorbitol as a key humectant and SLS as a standard surfactant/foaming agent in toothpaste.
Senthilkumar et al. (2022)	Herbal toothpaste from natural sources	Used glycerine as humectant and mint oil as flavouring agent in a herbal toothpaste base.
Dhangar et al. (2023/2024)	Herbal tamarind-seed toothpaste	Incorporated Tamarindus indica seed powder as a natural abrasive.
Serrano et al. (2024)	Anthocyanin-based edible coatings	Identified effective film-forming polymer strategies for anthocyanin-containing systems.

3. MATERIALS AND METHODS

3.1 Materials and their Functions

Table 3. Function of key excipients used in the two formulations

Excipient	Function	Rationale
HPMC E15	Film-forming agent, thickener, binder	Forms smooth, flexible, transparent films with good bioadhesion in the oral cavity.
CMC-Na	Film-forming agent / thickener; mucoadhesive	Enhances mucoadhesion and viscosity of the casting solution / gel base.
Glycerine	Plasticizer, humectant, sweetener	Reduces film brittleness and prevents drying out.
Sorbitol	Humectant, sweetening agent	Prevents moisture loss and improves palatability.
PEG 400	Plasticizer, solvent, humectant	Increases film flexibility.
Sodium lauryl sulfate (SLS)	Foaming/surfactant agent	Improves surface wetting and generates foam in the toothpaste.
Calcium carbonate	Abrasive, polishing agent	Mohs hardness ≈3, below enamel hardness (≈5), enabling plaque removal without enamel erosion.
Tamarind seed powder	Natural abrasive	GRAS-recognised natural alternative/adjunct abrasive.
Citric acid	pH adjuster	Adjusts final formulation pH (target 6.5–7.5) and helps stabilise the anthocyanin pigment.
Xanthan gum	Thickening agent	Imparts pseudoplastic rheology suited to a toothpaste base.
Peppermint/mint oil	Flavouring agent	Masks the characteristic herbal taste of the extract; improves patient acceptability.
Butterfly pea flower extract	Active optical colour-correcting agent, natural colourant, antioxidant	Principal ternatin-anthocyanin source responsible for the violet–blue colour correction.

3.2 Preparation of butterfly pea flower anthocyanin extract

- Harvested flowers were sun-dried for 48 hours.
- Dried flowers were ground into a coarse powder.
- The powder was extracted with water at 80 °C for 1 hour.
- The extract was filtered to obtain a clear filtrate.
- The filtrate was concentrated by solvent evaporation at 60 °C
- The concentrated extract was stored in an amber (light-protected) container.

3.3 Pre-formulation studies

Organoleptic evaluation of the raw extract indicated a deep blue/purple colour (pH-dependent), a mild characteristic herbal odour, and a slightly bitter/astringent taste. Solubility of the anthocyanin extract was assessed in distilled water, ethanol, and buffer solutions across pH 3–8, with maximum colour stability observed under acidic conditions (pH 3–5); the extract appeared red/pink at acidic pH, purple/blue at neutral pH, and faded greenish under alkaline conditions, consistent with the known pH-dependent chromic behaviour of anthocyanins.

3.4 Formulation of the dissolving whitening strips

Table 4. Composition of the dissolving whitening strip formulation

Ingredient	Function	Quantity
HPMC E15	Film-forming agent, thickener, binder	3 g
CMC-Na	Film-forming agent, mucoadhesive, thickener	1 g
Glycerine	Plasticizer, humectant	1.5 mL
Sorbitol	Humectant, sweetening agent	1.5 mL
PEG 400	Plasticizer, solvent, humectant	2 mL
Butterfly pea flower extract	Active optical colour-correcting agent, natural colorant	15 mL
Mint oil	Flavouring agent	q.s.

Preparation proceeded in five stages: (1) preparation of the polymer solution — HPMC dispersed with continuous stirring in purified water at 40–50 °C, followed by gradual addition of CMC-Na and hydration for 30 minutes; (2) addition of plasticisers/humectants (glycerine, sorbitol, PEG 400) with continuous stirring; (3) separate dissolution of the butterfly pea extract in a small volume of purified water, protected from light, and its incorporation into the polymer mixture with gentle stirring to obtain a uniform purple solution; (4) addition of mint oil, followed by a 10–15 minute deaeration period to remove entrapped air, casting onto a clean glass plate/Petri dish, and drying at room temperature or in a hot-air oven at 40–45 °C until a flexible, non-sticky film formed; and (5) peeling and cutting of the dried film into strips of 6 × 1.5 cm (female-sized) or 7 × 1.5 cm (male-sized).

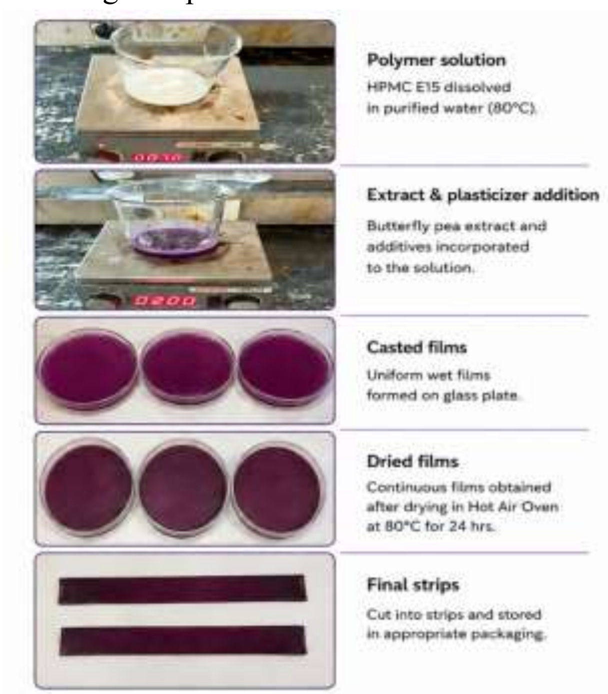

Figure 2. Stepwise preparation of anthocyanin-based dissolving whitening strips

3.5 Formulation of the herbal purple toothpaste

Table 5. Composition of the herbal purple toothpaste formulation

Ingredient	Function	Quantity
Calcium carbonate	Abrasive, polishing agent	15 g
Glycerine	Humectant, sweetener	15 mL
Sorbitol	Humectant, sweetener	40 mL
Tamarind seed powder	Abrasive	1 g
Sodium lauryl sulfate (SLS)	Foaming agent	1 g

Butterfly pea flower extract	Natural colorant, antioxidant	20 mL
Peppermint oil	Flavouring agent	0.3 mL
CMC-Na	Thickener	1 g
Purified water	Solvent, vehicle	q.s.

The gel base was prepared by hydrating CMC-Na into a sorbitol–glycerine mixture with continuous stirring for approximately 30 minutes until smooth. Purified water was then added gradually under stirring, followed by gradual incorporation of calcium carbonate and tamarind seed powder to ensure uniform dispersion. SLS was added slowly to minimise excessive foam generation during mixing, followed by the butterfly pea extract with continuous stirring until a uniform purple colour developed. Sweetening and flavouring agents were then incorporated, the pH was adjusted with citric acid solution and the final homogeneous paste was packaged into tubes and stored at room temperature.

Figure 3. Stepwise preparation of herbal purple toothpaste

4. EVALUATION PARAMETERS AND TESTS

Dissolving whitening strips: physical appearance (colour, transparency, surface texture, dimensions, weight uniformity, edge integrity); thickness (Vernier calliper, multiple measurement points); folding endurance (repeated folding at a single point until fracture); disintegration time (in artificial saliva, simulating oral conditions); tensile strength (maximum stress before breaking); and surface pH (moistened strip surface tested with pH paper/electrode).[6,12,13]

Herbal purple toothpaste: organoleptic properties (colour, odour, taste, texture, consistency, phase separation) by sensory/visual assessment; foaming ability (foam volume generated on shaking a fixed toothpaste quantity in water, recorded initially and after 1 minute); spreadability (area of spread of a fixed quantity of toothpaste under increasing applied load, using an ointment/spreadability test apparatus); pH (of an aqueous dispersion of the toothpaste); and short-term stability (colour, odour, texture, pH, spreadability, foaming, phase separation and microbial growth monitored at Day 0, 7, 15 and 30 under room-temperature storage).[14,15,16,17]

4.1 Part A — Dissolving whitening strips

Table 6. Physical appearance of the dissolving whitening strips

Attribute	Observation	Remark
Colour	Uniform violet-blue	Characteristic of butterfly pea extract; pass
Transparency	Translucent to semi-transparent	Acceptable for a film-type formulation
Surface texture	Smooth, glossy on the release-liner side	No pitting, cracks, or air bubbles

Dimensions (L × W)	65 mm × 15 mm	Within intended design specification
Weight uniformity	Mean 0.148 ± 0.012 g (CV 8.1%)	Acceptable; CV < 10%
Edge integrity	Clean, no fraying or tears	Pass

The strips displayed a uniform, characteristic violet-blue colour attributable to the anthocyanin content of the butterfly pea extract, with a smooth, defect-free surface and acceptable weight uniformity (CV < 10%), indicating a consistent casting process.

Table 7. Thickness measurement of the whitening strips (Vernier calliper)

Measurement point	Thickness (mm)
Centre	0.11
Top-left	0.10
Top-right	0.12
Bottom-left	0.09
Mean ± SD	0.105 ± 0.011 mm

Table 8. Folding endurance of individual whitening strips

Strip	S1	S2	S3	S4	S5	Mean
Folds withstood	278	312	295	263	301	289.8

A mean folding endurance of 289.8 folds indicates good mechanical flexibility, consistent with the plasticising combination of glycerine and PEG 400 alongside the HPMC/CMC film-forming matrix.

Artificial saliva (disintegration-testing medium)

Table 9. Composition of artificial saliva used for strip disintegration testing (per 1000 mL)

Ingredient	Quantity	Role
Sodium chloride (NaCl)	8.00 g	Electrolyte - mimics salivary sodium
Potassium chloride (KCl)	0.20 g	Electrolyte - mimics salivary potassium
Disodium hydrogen phosphate (Na_2HPO_4)	1.15 g	Buffer - maintains pH
Potassium dihydrogen phosphate (KH_2PO_4)	0.20 g	Buffer
Calcium chloride ($CaCl_2$)	0.10 g	Mimics salivary calcium
Magnesium chloride ($MgCl_2$)	0.05 g	Trace electrolyte
Purified water	q.s. to 1000 mL	Vehicle
Final pH	6.8 ± 0.1 (adjusted with 0.1 N NaOH/ HCl)	—

Table 10. Disintegration time of the whitening strips in artificial saliva

S1	S2	S3	S4	S5	S6	Mean	Range
10:30	11:15	10:45	12:00	11:30	10:00	11:00 min	10–12 min

A mean disintegration time of 11 minutes (range 10–12 minutes) is considered satisfactory for a dissolving whitening strip, providing sufficient tooth-surface contact time to allow optical colour correction before the film fully dissolves.

Surface pH: A surface pH of 6.3 (acceptable range of 6.0–6.5), obtained by wetting the strip with 0.5 mL of purified water and applying pH paper after 1 minute.

4.2 Part B — Herbal purple toothpaste

Table 11. Organoleptic properties of the herbal purple toothpaste

Parameter	Observation	Standard/ expected	Remark
Colour	Violet-purple (characteristic)	Any uniform colour	Pass
Odour	Mild peppermint fragrance	Characteristic, pleasant	Pass
Taste	Mildly sweet, cool	Palatable, non-bitter	Pass
Texture	Smooth, homogeneous paste	No lumps or grit	Pass
Consistency	Semi-solid, non-watery	Adequate body	Pass
Phase separation	Absent	Absent	Pass

All organoleptic parameters were satisfactory. The violet-purple colour was visually appealing and the peppermint flavour masked the characteristic herbal taste of the extract, which is expected to support patient acceptability and compliance.

Table 12. Foaming ability of the toothpaste

Parameter	Observation
Initial foam volume	24 mL
Foam volume after 1 min	18 mL
Foam retention	75%
Foam quality	Moderate, fine-bubbled
Acceptability	Satisfactory

Table 13. Spreadability of the toothpaste under increasing applied load.

Load applied	Area of spread (cm^2)
0 g (self-weight)	3.8
10 g	5.2
20 g	7.1

Toothpaste pH: A pH of 6.2 (acceptable range 6.0–6.5), each obtained on an aqueous dispersion of the toothpaste. The spreadability data show a progressive increase in spread area with applied load in both sources, consistent with pseudoplastic (shear-thinning) rheological behaviour appropriate for a toothpaste.

Table 14. Short-term stability of the herbal purple toothpaste (room temperature).

Parameter	Day 0	Day 7	Day 15	Day 30
Colour	Violet-purple	Violet-purple	Slight fade	Slight fade
Odour	Mild, pleasant	Mild, pleasant	Mild, pleasant	Mild, pleasant
Texture	Smooth, creamy	Smooth, creamy	Slightly thicker	Slightly thicker
pH	7.1	7.1	6.9	6.7
Spreadability	Good	Good	Good	Good
Foaming	Moderate	Moderate	Moderate	Moderate
Phase separation	Absent	Absent	Absent	Absent
Microbial growth	Nil	Nil	Nil	Nil

The toothpaste remained physically stable over the 30-day observation period, with a slight colour fade and a modest downward drift in pH from Day 15 onward, consistent with the known pH- and light-sensitivity of anthocyanin pigments. No phase separation or microbial growth was observed across the study period.

5. DISCUSSION

The present study successfully formulated and evaluated a herbal purple toothpaste and a dissolving whitening strip containing butterfly pea flower (*Clitoria ternatea*) anthocyanin as a natural optical colour-correcting agent. Both formulations exhibited satisfactory physicochemical properties and short-term stability, indicating the suitability of anthocyanin for peroxide-free whitening formulations.[1,2,20]

The dissolving whitening strips showed acceptable thickness, folding endurance, disintegration time, and surface pH, demonstrating that the HPMC–CMC polymer system produced flexible and stable oral films. These findings are consistent with previous reports on HPMC/CMC-based oral dissolving films.[6,12,13]

The herbal toothpaste demonstrated acceptable organoleptic properties, pH, foaming ability, spreadability, and remained physically stable throughout the 30-day study. The slight colour fading observed during storage is consistent with the known pH- and light-sensitivity of anthocyanins.[9,15,16,20]

Overall, the findings suggest that butterfly pea flower anthocyanin is a promising natural alternative to synthetic colourants for temporary optical tooth whitening. However, further studies involving objective colour analysis, long-term stability, and clinical evaluation are required to establish its whitening efficacy and commercial applicability.

6. NOVELTY OF THE STUDY

The principal novelty of this work lies in the substitution of the synthetic colourants used in many marketed purple whitening products (e.g., blue covarine, PAP dyes) with a fully edible, GRAS-recognised, Ayurvedic-origin anthocyanin source, butterfly pea flower (Clitoria ternatea) as the active optical colour-correcting pigment, in two complementary formats (a dissolving strip for sustained contact and a toothpaste for routine daily use).[2,7,18,20]

Table 15. FLORAWHITE positioning relative to marketed synthetic purple whitening products.

Feature	Marketed purple strips/pastes	FLORAWHITE (this study)
Pigment source	Synthetic (blue covarine, PAP dyes)	Natural — butterfly pea flower (C. ternatea)
Edible / food-grade	Not edible	Fully edible, GRAS-recognised anthocyanin
Herbal origin	None	Ayurvedic plant, traditional use documented
Peroxide content	Some contain PAP or H_2O_2	Completely peroxide-free
Antioxidant benefit	None	Anthocyanins provide oral antioxidant activity
pH-responsive colour	Fixed synthetic colour	Natural purple at oral pH ~6.5–7.0

Positioning this formulation strategy within a rigorous pharmaceutical evaluation framework (physicochemical, mechanical, and short-term stability testing, rather than purely cosmetic/consumer testing) is itself a modest contribution, distinguishing this work from purely commercial or descriptive accounts of butterfly-pea-based cosmetics.

7. LIMITATIONS

- The strip's dimensions (6–7 cm × 1.5 cm) may not conform to all arch widths and tooth sizes.
- The formulations provide optical (temporary) whitening through colour correction and do not chemically bleach or permanently remove tooth stains.
- No clinical studies or human volunteer trials were conducted; therefore, clinical efficacy, user acceptability, and long-term safety could not be established.
- No objective colour analysis (e.g., spectrophotometric measurements or CIELAB ΔE values) was performed to quantitatively assess the whitening effect.
- Only a short-term stability study was carried out; long-term stability under recommended storage conditions was not evaluated.

- The anthocyanin content of the butterfly pea flower extract was not quantified using analytical techniques such as UV–Visible spectroscopy or HPLC.
- The stability of anthocyanins against factors such as light, temperature, and pH was not analytically investigated, although these factors are known to influence pigment stability.
- The formulations were evaluated mainly for physicochemical properties (appearance, pH, thickness, folding endurance, disintegration time, foaming ability, spreadability, and short-term stability), while advanced characterization studies were not performed.
- Antimicrobial activity against oral microorganisms was not evaluated.
- Enamel safety was not experimentally assessed through hardness testing, surface morphology analysis, or erosion studies.
- The formulations were developed only at the laboratory scale; industrial scale-up, manufacturing optimization, and process validation were beyond the scope of the study.
- Comparative studies with marketed whitening products were not performed to directly assess relative efficacy and performance.
- Long-term whitening durability after repeated use was not investigated.

8. FUTURE SCOPE

- Incorporate additional herbal actives (e.g., neem, turmeric) and develop multi-layer strips with sustained pigment release.
- Conduct controlled clinical or in vitro stained-enamel studies to assess cumulative whitening effect over 4–12 weeks, benchmarked against commercial purple and peroxide-based products.
- Develop microencapsulation techniques for anthocyanins to enhance pigment photostability and pH-stability, extending shelf life.
- Explore AI-assisted digital tooth-shade matching and personalised formulation/strip-size recommendations.
- Optimise packaging (opacity, barrier properties) to minimise light- and moisture-induced pigment degradation.
- Undertake complete spectroscopic characterisation (UV-Vis, FTIR), content-uniformity assays, and accelerated stability studies to close the data gaps identified in this manuscript.

9. CONCLUSION

This study demonstrates the formulation and preliminary evaluation of a herbal purple toothpaste and a dissolving whitening strip using butterfly pea flower (Clitoria ternatea) anthocyanin extract as a peroxide-free, natural optical colour-correcting agent. Both formulations exhibited satisfactory physicochemical, mechanical and short-term stability properties, supporting the feasibility of anthocyanin-based purple whitening products as a safer, edible-grade, herbal alternative to synthetic colour-correcting whitening systems. Confirmatory whitening-efficacy testing, spectroscopic characterisation, and longer-duration stability and safety studies are required to substantiate the products' cosmetic claims and to support eventual clinical or commercial translation.

Figure 4. Final FLORAWHITE formulations with packaging

10. ACKNOWLEDGEMENTS

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11. CONFLICT OF INTEREST

The authors declare no conflict of interest.

12. AUTHOR CONTRIBUTIONS

Conceptualisation and supervision: Suvidha S. Kabadi. Formulation development, evaluation, data acquisition and drafting: Vaibhavee P. Shinde, Dravinkumar R. Singh, Garima D. Singh, Sahil S. Sondkar. Co-Guide: Sanket S. Gabhale

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