



Formulation and Evaluation of Fast Dissolving Tooth paste Tablet By Utilizing Incinerated *Achyranthes aspera* Ash

Apsar mussjammal .A* and Shanthi.P

K.M. College of Pharmacy, The Tamil Nadu Dr. M.G.R. Medical University, Chennai, TamilNadu, India.

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ABSTRACT

Conventional tube toothpaste generates enormous, largely non-recyclable plastic waste and depends on water for use, which has prompted interest in solid, waterless dentifrice formats. In this study a herbal chewable tooth tablet was formulated using the calcined ash of *Achyranthes aspera* (Apamarga Kshar), a plant used traditionally in Indian oral-care practice, as the principal abrasive and mineral-rich active ingredient. Tablets were prepared by direct compression using mannitol and calcium carbonate as diluents, microcrystalline cellulose as a binder/filler, xylitol as a non-cariogenic sweetener, a peppermint–menthol–clove flavour system, talc and magnesium stearate as lubricant/glidant, and crospovidone and croscarmellose sodium as superdisintegrants. Six trial formulations (F1–F6) were prepared by varying the ratio of the two superdisintegrants while holding total tablet weight constant at 300 mg. Pre-compression (bulk density, tapped density, Carr's index, Hausner ratio, angle of repose) and post-compression (weight variation, thickness, hardness, friability, wetting time, water absorption ratio, *in-vitro* disintegration and dissolution, drug content, moisture content, surface pH and foaming ability) parameters were evaluated, together with herbal-specific tests (ash value, particle size distribution, antimicrobial activity against oral pathogens) and Fourier-transform infrared (FTIR) drug–excipient compatibility studies. A preliminary optimization matrix, followed by Central Composite Design (CCD) and Box–Behnken Design (BBD) response-surface modelling, was used to study the combined effect of crospovidone and croscarmellose sodium (and, in the BBD, compression force) on tablet hardness and disintegration time. Formulation F5 (crospovidone 10 mg, croscarmellose sodium 8 mg per 300 mg tablet) gave the most balanced profile, combining adequate hardness (~4.0–4.5 kg/cm²), rapid disintegration (24–32 s), low friability (<0.6% w/w), acceptable surface pH (7.15 ± 0.03), optimal foaming, and the highest *in-vitro* drug/marker release, and was carried forward as the optimized batch. FTIR spectra of the ash and the optimized tablet showed no loss or shift of the characteristic functional-group bands of the ash, indicating drug–excipient compatibility. These findings support the technical feasibility of a plant-ash–based, direct-compression tooth tablet as a low-plastic, water-saving alternative to conventional paste dentifrice, while highlighting the need for confirmatory clinical and full stability data before commercial translation.

Introduction

Oral health is a core component of general health and quality of life, underpinning speech, mastication, nutrition and social confidence. The oral cavity is lined by a specialised mucosa and irrigated continuously by saliva, which lubricates tissue, buffers acid, promotes enamel remineralisation and, through enzymes and immunoglobulins, restrains pathogenic overgrowth [1–5]. More than 700 microbial species inhabit the mouth in a normally balanced ecosystem; when this balance is disturbed by poor hygiene, high sugar intake, smoking, systemic disease or reduced salivary flow, dental plaque – a structured biofilm – accumulates and predisposes to caries, gingivitis, periodontitis and halitosis [5–9].

The conventional response to this risk, a fluoride tube toothpaste used with a toothbrush and running water, is

effective but environmentally costly. It has been estimated that the United Kingdom alone consumes on the order of 300 million toothpaste tubes annually – laid end to end, equivalent to roughly twice the circumference of the globe – and that a typical multilaminate tube, often incorporating a thin aluminium barrier layer, can take on the order of 500 years to degrade in landfill while remaining very difficult to recycle at scale [1,2]. Toothpaste use is also inseparable from running water in most consumer habits, adding a second sustainability burden. These concerns, together with a broader consumer shift toward “waterless” and solid personal-care formats, have renewed interest in compressed chewable tooth tablets: a unit-dose solid dentifrice that is bitten, chewed briefly to disintegrate and disperse in saliva, and brushed in, without need for a separate paste and, in principle, with markedly less packaging waste [17,19,22,29].

* Corresponding author

✉: Apsar Mussjammal .A: apsarappas1@gmail.com

In parallel with this packaging-driven interest, herbal oral-care ingredients have attracted growing scientific attention because many medicinal plants possess antimicrobial, antioxidant, anti-inflammatory and wound-healing activity that is directly relevant to plaque control and gingival health [18,20,21]. *Achyranthes aspera* Linn. (Amaranthaceae), known in Ayurveda as Apamarga and in Hindi as Latjeera, is an erect or procumbent annual/perennial herb found widely as a roadside weed across India and other tropical regions [77–85]. Various parts of the plant - root, shoot and seed - are used traditionally for antiperiodic, diuretic, purgative, laxative, antiasthmatic, antimicrobial and hepatoprotective purposes, and phytochemical work has isolated saponins, oleanolic acid, alkaloids, long-chain compounds and other bioactive constituents from the plant [86–108]. In Ayurvedic practice the whole plant is traditionally incinerated under controlled conditions to yield an alkaline ash, “Apamarga Kshar,” which is used topically for oral and dental complaints and is reported to be rich in mineral content (notably calcium and potassium) with astringent and antimicrobial properties relevant to gum health [66,119].

Building on this traditional use, the present work explores *Achyranthes aspera* ash as the principal active/abrasive ingredient of a directly compressed, fast-disintegrating tooth tablet. Direct compression was selected as the manufacturing route because it avoids granulation solvents and heat, is simple to scale, and is compatible with moisture-sensitive herbal actives [143,144]. Two pharmacopoeial superdisintegrants, croscopovidone and croscarmellose sodium, were varied systematically to identify a blend that disintegrates rapidly in the mouth (mimicking the ultra-rapid breakdown required of orally disintegrating tablets [146,153]) while retaining sufficient mechanical hardness for handling and packaging. The specific objectives of the study were to: (i) collect, authenticate and process *Achyranthes aspera* into a fine, reproducible ash; (ii) select a compatible excipient system for a palatable, mineral-rich tooth tablet; (iii) formulate six trial batches (F1–F6) by direct compression and characterise their pre- and post-compression properties; (iv) confirm drug–excipient compatibility by FTIR and characterise the ash by particle size and antimicrobial testing; (v) apply Central Composite and Box–Behnken response-surface designs to rationalise the superdisintegrant ratio (and, for the BBD, compression force) against hardness and disintegration time; and (vi) select and profile an optimized batch as a candidate for further pilot-scale and stability evaluation.

Materials and Methods

Plant Collection, Authentication and Preparation of Ash

Whole plants of *Achyranthes aspera* were collected from the local vicinity of Madurai, Tamil Nadu, India, and authenticated by a qualified botanist; a voucher herbarium specimen was prepared and retained (Figure 1). The collected material was washed thoroughly with deionised water to remove adhering soil and extraneous matter, and shade dried at room temperature for 7–10 days to protect heat-labile constituents and limit microbial

growth. The dried plant was pulverised using a mechanical grinder and passed through a #40 mesh sieve. The resulting coarse powder was packed into a silica crucible and incinerated in a muffle furnace at $600 \pm 10^\circ\text{C}$ for 1 hour 45 minutes under controlled conditions to obtain *Achyranthes aspera* ash (Apamarga Kshar). The ash was cooled in a desiccator, sieved to a uniform fine powder, and stored in an airtight container protected from moisture until use (Figure 2).

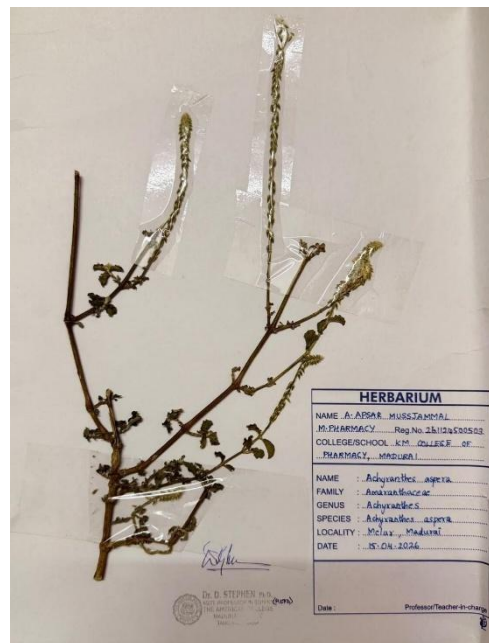


Figure 1. Authenticated herbarium voucher specimen of *Achyranthes aspera* used as the source plant material for ash preparation.



Figure 2. *Achyranthes aspera* dried aerial plant material (right) and the fine, greyish incinerated ash, Apamarga Kshar (left), used as the active abrasive/mineral ingredient of the tooth tablet.

Materials

Achyranthes aspera ash was used as the active ingredient. Mannitol and calcium carbonate served as diluent/mouthfeel and mild-abrasive agents respectively; microcrystalline cellulose (MCC) was used as a binder/filler; xylitol was included as a non-cariogenic sweetener; croscopovidone and croscarmellose sodium were used as superdisintegrants; peppermint powder, menthol crystal and clove powder constituted the flavouring system; and talc and magnesium stearate served as glidant and lubricant, respectively. All excipients were of pharmacopoeial grade and were selected with reference to the Handbook of Pharmaceutical Excipients [118].

Formulation of Tooth Tablets by Direct Compression

Six trial formulations (F1–F6) of 300 mg total tablet weight were designed by systematically varying the quantities of crospovidone and croscarmellose sodium while keeping all other excipients constant (Table 1), in order to study the influence of superdisintegrant type/ratio on tablet hardness and disintegration time. For each batch, *Achyranthes aspera* ash and the excipients were individually passed through a #60 mesh sieve, blended geometrically in ascending order of weight in a polybag blender for 15 minutes, and lubricated with talc and magnesium stearate for a further 3 minutes. The lubricated blend was compressed using a direct-compression tablet press fitted with flat-faced round punches to a target weight of 300 mg per tablet.

Table 1. Quantitative composition of the six trial herbal tooth-tablet formulations (F1–F6) prepared by direct compression; crospovidone and croscarmellose sodium were the two variables systematically studied.

Ingredient (mg/tablet)	F1	F2	F3	F4	F5	F6
Mannitol	132	128	134	126	130	131
Microcrystalline cellulose (MCC)	60	60	60	60	60	60
Crospovidone	6	14	–	–	10	5
Croscarmellose sodium	10	6	14	22	8	5
Calcium carbonate	40	40	40	40	40	40
Xylitol	20	20	20	20	20	20
Peppermint powder	2	2	2	2	2	2
Menthol crystal	5	5	5	5	5	5
Clove powder	2	2	2	2	2	2
Talc	1	1	1	1	1	1
Magnesium stearate	2	2	2	2	2	2
<i>Achyranthes aspera</i> ash	20	20	20	20	20	20
Total tablet weight (mg)	300	300	300	300	300	300

Pre-Compression (Powder Flow) Evaluation

The bulk powder blends were evaluated prior to compression to predict die-filling efficiency and, in turn, tablet weight and content uniformity [129–131,141,142]. Bulk density (ρ_b) was calculated as the ratio of powder mass to its unsettled (poured) volume in a graduated cylinder, and tapped density (ρ_t) as the ratio of mass to the constant volume obtained after mechanical tapping. Carr's compressibility index was calculated as $100 \times (\rho_t - \rho_b) / \rho_t$, and the Hausner ratio as ρ_t / ρ_b . The angle of repose was measured by the fixed-funnel method,

allowing the powder to flow freely onto a flat surface to form a cone and calculating $\theta = \tan^{-1}(h/r)$, where h and r are the cone height and base radius. Flow character was classified against standard USP/IP scales (excellent, good, passable, poor).

Drug–Excipient Compatibility (FTIR)

Compatibility between *Achyranthes aspera* ash and the selected excipients was assessed by Fourier-transform infrared (FTIR) spectroscopy using the potassium bromide (KBr) pellet technique [132–136]. Spectra of the pure ash, a 1:1 physical mixture of ash with the optimized batch excipients, and the compressed optimized tablet were recorded on a Shimadzu FTIR-8400S spectrophotometer over the range 4000–400 cm^{-1} . Samples were triturated with dry IR-grade KBr (approximately 1:100 w/w) and compressed at 5.5 metric tons into transparent pellets. Spectra of the physical mixture/tablet were compared with that of the pure ash for retention, shift or disappearance of characteristic absorption bands as evidence of compatibility or interaction.

Post-Compression Evaluation of Tablets

Weight variation was determined by individually weighing 20 tablets on an analytical balance (Figure 3) and comparing the deviation of each from the mean against IP/USP limits for tablets of this weight class. Thickness and diameter were measured for 10 tablets using a digital vernier caliper. Hardness (crushing strength) was measured for 6 tablets using a tablet hardness tester and expressed in kg/cm^2 . Friability was determined on a Roche friabilator by tumbling a sample of dedusted tablets (equivalent to 6.5 g) for 100 revolutions at 25 rpm and calculating percentage weight loss; a limit of <1% w/w was applied [145].

Wetting time was measured by placing a tablet on a piece of tissue paper folded twice and placed in a Petri dish containing 6 mL of water with a water-soluble dye, and recording the time for water to reach the upper surface of the tablet (Figure 4). The water absorption ratio (R) was calculated as $R = 100 \times (W_a - W_b) / W_b$, where W_b and W_a are tablet weights before and after water absorption.

In-vitro disintegration time was determined by the petri-dish method, placing a tablet on wetted Whatman No. 1 filter paper in 10 mL of pH 6.8 phosphate buffer/simulated saliva at 37 ± 0.5 °C and recording the time to complete breakdown into fine, non-aggregated particles without mechanical agitation [147,148].

In-vitro dissolution/marker release and drug (marker) content were determined by UV-Vis spectrophotometry at the analytical wavelength of the marker constituent ($\lambda_{\text{max}} \approx 282$ nm), referencing a standard calibration curve constructed from five working concentrations [137–140,158,161]. Moisture content was determined gravimetrically by loss-on-drying at 105 °C to constant weight [128,149]. Surface pH was measured by allowing a tablet to swell in 1 mL of distilled water for 1 minute and contacting the surface with a calibrated digital pH electrode. Foaming ability was assessed by agitating a tablet in a fixed volume of water in a graduated cylinder and recording the height of foam generated after a standard interval.



Figure 3. Weighing of the herbal tooth tablets on an analytical balance during the weight-variation test.



Figure 4. Representative wetting-time test: tablet immediately after contact with water (left, 0 min) and after complete surface wetting (right, ~30 min endpoint shown for illustration of the test set-up).

Herbal-Specific and Safety Evaluations

Ash value of the raw *Achyranthes aspera* material was determined by the standard incineration method of the Indian Pharmacopoeia [124].

Particle size distribution of the ash and powder blends was assessed by analytical sieving using a stack of USP test sieves (#40, #60, #80, #100, #120, #200 and pan) agitated for 15 minutes, with the target that the bulk of the material should pass a #80 sieve (<180 μm) for gentle, non-abrasive enamel contact [159].

Antimicrobial activity of the ash was screened against representative oral pathogens (e.g., *Streptococcus mutans*, *Lactobacillus* spp. and *E. coli* as a reference organism) by the agar-well diffusion method, comparing zones of inhibition across ash concentrations.

Heavy-metal analysis (lead, cadmium, arsenic, mercury) of the optimized formulation was carried out by acid microwave digestion followed by atomic absorption/ICP-based spectrometry and compared with WHO/AYUSH/USP <233> limits [156,157].

Mineral content (calcium, potassium, magnesium, sodium) of the ash was profiled by ICP-OES following acid digestion [160]. Oral mucosal irritation and microbial-limit testing were also performed on the optimized batch as part of the overall safety package [154,156].

Design of Experiments: Preliminary Screening, CCD and BBD

A preliminary **2-factor screening** (the six F1–F6 batches) was used to identify a workable range for crospovidone (X1) and croscarmellose sodium (X2), with hardness (Y1) and disintegration time (Y2) as responses. This range was then used to build a two-factor, five-level rotatable Central Composite Design (CCD) comprising 4 factorial points, 4 axial points ($\alpha = 1.414$) and 5 replicated centre points (13 runs total), from which second-order polynomial models were fitted for Y1 and Y2 and response-surface/contour plots were generated.

A three-factor, three-level **Box–Behnken Design** (BBD) (15 runs: 12 edge-midpoints + 3 centre points) was subsequently used to add compression force (X3) as a third variable and to confirm the optimum region identified by the CCD without testing extreme corner/axial combinations that could risk capping or lamination. Model adequacy was assessed by ANOVA (significance of the quadratic model, non-significant lack-of-fit) and the coefficient of determination (R^2). Half-normal probability plots and multiple regression were additionally used on the F1–F6 data set to rank the relative influence of crospovidone and croscarmellose sodium on hardness and disintegration time at the 5% level of significance.

Stability Studies

The optimized formulation was packed into moisture-protective strip/blister packaging and stored under long-term ($25 \pm 2^\circ\text{C}$ / $60 \pm 5\%$ RH) and accelerated ($40 \pm 2^\circ\text{C}$ / $75 \pm 5\%$ RH) conditions in accordance with ICH Q1A(R2) [134,150]. Samples were withdrawn at 0, 1, 2 and 3 months and re-evaluated for organoleptic appearance, weight variation, hardness, friability, disintegration time, wetting time, foaming capacity, surface pH and marker content, against pre-defined acceptance ranges (hardness 3.0–5.0 kg/cm²; disintegration <60 s; content 95–105%; pH 6.5–7.5).

Statistical Analysis

All *in-vitro* evaluations were performed in replicate and are expressed as mean $\pm$ SD where applicable. Response-surface regression, ANOVA and half-normal effect screening were used to analyse the design-of-experiments data as described in Section 2.8, at a significance level of $\alpha = 0.05$.

Results and Discussion

Plant Authentication and Ash Yield

The collected specimen was confirmed as *Achyranthes aspera* Linn. (family Amaranthaceae) on botanical authentication (Figure 1), and controlled incineration of the shade-dried plant material at $600 \pm 10^\circ\text{C}$ for 1 h 45 min yielded a fine, greyish alkaline ash (Figure 2) suitable for direct use as a tablet ingredient after sieving.

Pre-Compression (Powder Flow) Properties

The consolidated flow data for the six powder blends are summarised in Table 2 and Figure 5. Bulk density ranged narrowly from 0.44–0.49 g/cm³ and tapped density from 0.55–0.56 g/cm³ across batches, indicating a relatively consistent particle packing behaviour. Carr's index ranged from 10.9% (F2, excellent) to 21.4% (F3 and F6, passable), and the Hausner ratio from 1.12 to 1.27, broadly tracking the same trend. Angle of repose values of 27.6–33.2° corresponded to good-to-passable flow on the standard classification scale. Blends richer in croscarmellose sodium relative to crospovidone (F3, F6) tended toward the poorer end of the flow spectrum, while F2 (higher crospovidone) gave the most favourable packing and flow indices. Formulation F5, the eventual optimized batch, showed good flow (Carr's index 16.7%, Hausner ratio 1.19, angle of repose 28.4°), adequate for reliable die filling on direct compression.

Table 2. Pre-compression (powder flow) properties of the *Achyranthes aspera* ash/excipient blends F1–F6.

Batch	Bulk density (g/cm ³)	Tapped density (g/cm ³)	Carr's index (%)	Hausner ratio	Angle of repose (°)	Flow property
F1	0.45	0.55	18.18	1.22	30.8	Good
F2	0.49	0.55	10.91	1.12	27.6	Excellent
F3	0.44	0.56	21.43	1.27	33.2	Passable
F4	0.46	0.55	16.36	1.20	29.5	Good
F5	0.47	0.56	16.70	1.19	28.4	Good
F6	0.44	0.56	21.43	1.27	32.9	Passable

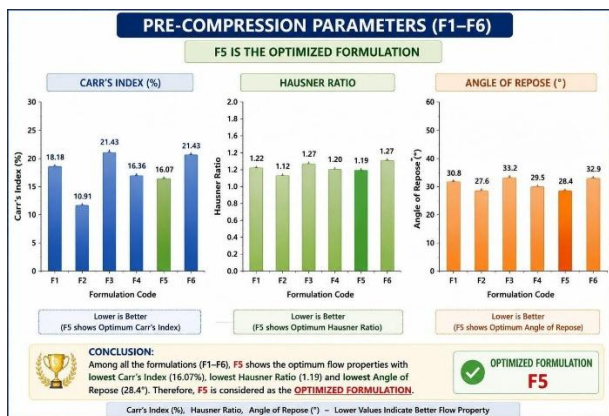


Figure 5. Comparative pre-compression flow properties (Carr's index, Hausner ratio and angle of repose) of formulations F1–F6; F5 combined good flow across all three indices.

Drug–Excipient Compatibility (FTIR)

FTIR spectra of the pure ash and of the optimized (F5) tablet are compared in Figure 6. The ash spectrum showed a broad O–H stretching band near 3418 cm⁻¹ (hydroxyl/adsorbed moisture), C–H stretching near 2924 cm⁻¹, an H–O–H bending band near 1638 cm⁻¹, a carbonate-associated C–C/C–O region around 1421 and 872 cm⁻¹, Si–O stretching near 1095 cm⁻¹ and metal–oxide/silicate bending bands below 720 cm⁻¹, consistent with a mixed mineral/carbonate ash matrix. In the compressed tablet spectrum, the corresponding O–H, aliphatic C–H,

carbonyl/aromatic and C–O/C–N region bands were all retained at essentially unshifted wavenumbers, with additional bands attributable to the added excipients (e.g., aryl–O and polysaccharide C–O stretching from cellulose and polyol excipients). The absence of newly generated peaks or loss of the ash's diagnostic bands supports physicochemical compatibility between the ash and the excipient system used in the optimized formulation.

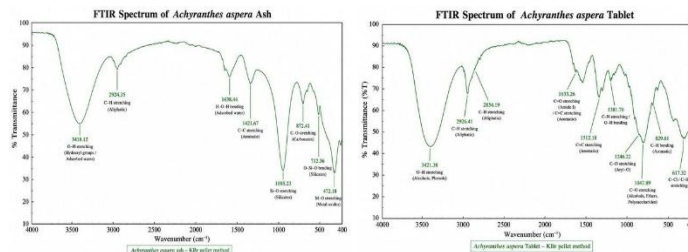


Figure 6. FTIR spectra of (left) pure *Achyranthes aspera* ash and (right) the optimized (F5) compressed tooth tablet, KBr pellet method. Principal functional-group assignments are annotated on each spectrum.

Post-Compression Physical Evaluation

All six batches met the pharmacopoeial weight-variation limit for tablets of this weight class, with mean tablet weights of 298.5–302.6 mg against a 300 mg target (Table 3). Tablet thickness was uniform (4.1–4.5 mm) and hardness ranged narrowly from 4.49–4.52 kg/cm² across all batches, indicating that the crospovidone/croscarmellose sodium ratio in the range studied did not compromise mechanical strength. Friability was low throughout (0.58–0.78% w/w) and, notably, was lowest for F5 (0.58%), comfortably meeting the conventional <1% acceptance limit (Figure 7).

Table 3. Weight variation, thickness, hardness and friability of tablets F1–F6.

Batch	Avg. weight (mg)	Thickness (mm)	Hardness (kg/cm ²)	Friability (% w/w)
F1	300.4	4.4	4.52	0.74
F2	299.8	4.1	4.50	0.69
F3	298.5	4.1	4.51	0.68
F4	301.5	4.2	4.49	0.63
F5	300.1	4.4	4.52	0.58
F6	302.6	4.5	4.52	0.78



Figure 7. Thickness (left) and hardness (right) of formulations F1–F6.

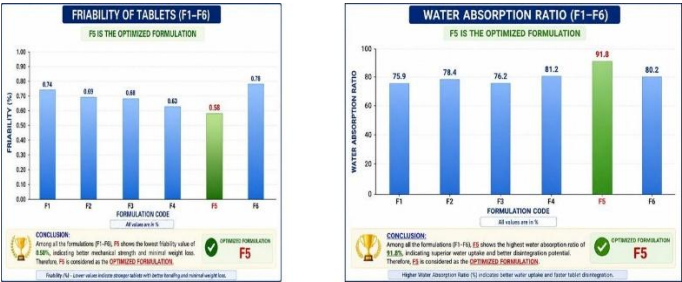


Figure 8. Friability (left) and water absorption ratio (right) of formulations F1–F6; F5 gave the lowest friability and the highest water absorption ratio.

Wetting, Disintegration, Dissolution and Drug (Marker) Content

Wetting time decreased with increasing crospovidone content, from 38s (F1) to a minimum of 24s for F5, consistent with the strong capillary wicking action of crospovidone relative to the swelling-dominated action of croscarmellose sodium. The water absorption ratio was correspondingly highest for F5 (91.8%), reflecting efficient liquid uptake into the tablet matrix (Table 4, Figure 8). *In-vitro* disintegration time by the petri-dish method ranged from 30–58s, with F5 disintegrating fastest (30s) and F6 (the lowest total superdisintegrant loading) slowest (58s); a duplicate disintegration run under slightly different conditions (Figure 10, right-hand panel) showed the same ordering. *In-vitro* marker release ranged from 90.1–98.2% across the batches, with F5 again the highest (98.2%), while drug/marker content uniformity was within the conventional 90–110% range for all batches and highest for F5 (98.8%) (Figure 9). Taken together, these performance parameters consistently favoured F5, in which a near-equal combination of crospovidone (10 mg) and croscarmellose sodium (8 mg) appears to provide synergistic disintegration without loss of hardness.

Table 4. Wetting time, water absorption ratio, *in-vitro* disintegration time, dissolution (marker release) and drug content of formulations F1–F6.

Batch	Wetting time (s)	Water absorption ratio (%)	Disintegration time (s)	Drug/marker release (%)	Drug content (%)
F1	38	75.9	33	96.5	96.2
F2	34	78.4	32	90.1	90.1
F3	26	76.2	38	95.1	94.1
F4	29	81.2	31	93.6	93.6
F5	24	91.8	30	98.2	98.8
F6	32	80.2	58	94.4	95.1

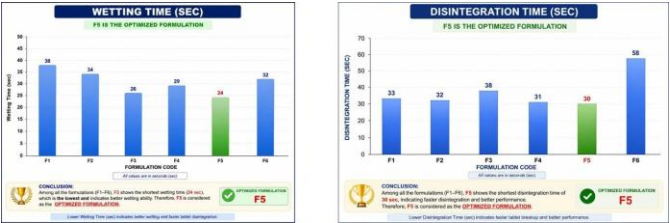


Figure 9. Wetting time (left) and *in-vitro* disintegration time (right) of formulations F1–F6; F5 shows the fastest wetting and disintegration.

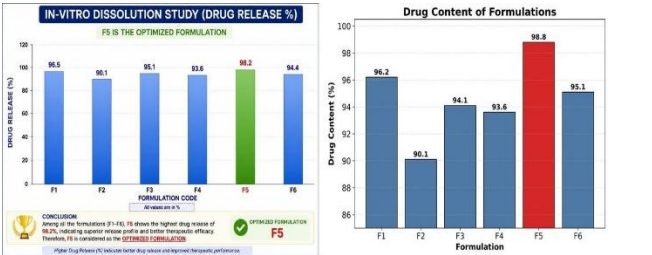


Figure 10. *In-vitro* dissolution/marker release (left) and drug content (right) of formulations F1–F6.

Moisture Content, Surface pH, Foaming Ability and UV Calibration

Loss-on-drying moisture content was low for all batches (1.1–1.8% w/w) and passed the internal specification of <2% for a compressed herbal solid dosage form, with F5 showing the lowest moisture content (1.1%), favourable for long-term physical stability (Figure 11). Surface pH of all batches fell within the 6.5–7.5 target range considered non-irritant to oral mucosa and enamel (F5: 7.15 ± 0.03). Foaming ability, assessed qualitatively from foam height after agitation, was rated optimal for F5 (13.0 ± 0.3 mL), balancing consumer-perceived cleansing sensation against the milder foam expected from a herbal, sulfate-free formulation (Figure 12). A five-point UV calibration curve for the *Achyranthes aspera* marker at 282 nm (10–50 µg/mL) showed a linear response (Table 5, Figure 13) and was used as the analytical basis for the dissolution and content-uniformity determinations in Sections 3.4–3.5.

Table 5. Moisture content (loss on drying), surface pH and qualitative foaming result for formulations F1–F6.

Batch	Moisture content (% LOD)	Surface pH (mean ± SD)	Foaming result
F1	1.5	7.12 ± 0.05	Mild
F2	1.8	7.05 ± 0.08	Good
F3	1.3	6.98 ± 0.04	Low
F4	1.6	7.20 ± 0.06	Good
F5	1.1	7.15 ± 0.03	Optimal
F6	1.4	6.90 ± 0.07	Minimal



Figure 11. Moisture content (left) and surface pH (right) of formulations F1–F6, both within acceptance limits for all batches.

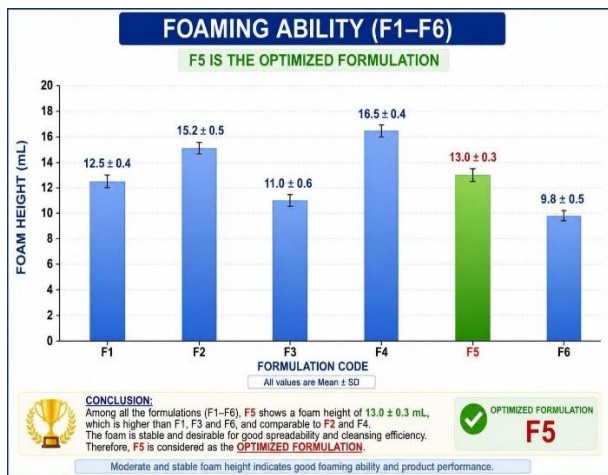


Figure 12. Foaming ability of formulations F1-F6; F5 gave an optimal, moderate foam consistent with a mild, sulfate-free herbal formulation.

Table 6. UV spectrophotometric calibration data for the *Achyranthes aspera* marker at 282 nm.

S.No.	Concentration (µg/mL)	Absorbance (282 nm)
1	10	0.030
2	20	0.069
3	30	0.110
4	40	0.131
5	50	0.152

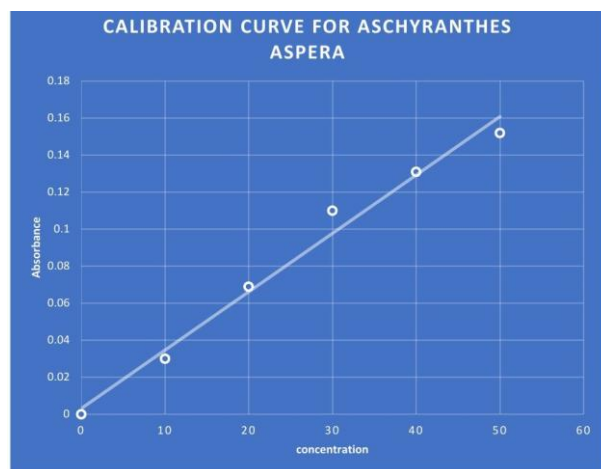


Figure 13. UV calibration curve for the *Achyranthes aspera* marker (10–50 µg/mL, 282 nm) used for dissolution and content-uniformity calculations.

Herbal-Specific Characterisation: Ash Value, Antimicrobial Activity and Particle Size

Ash-value determination on the raw plant material (Figure 14) confirmed a reproducible, pharmacopoeially consistent inorganic residue suitable for standardising the incineration process batch to batch. Agar-well diffusion testing of the ash against representative oral and reference organisms (Figure 15) showed measurable zones of inhibition, supporting the traditional use of Apamarga Kshar as an antimicrobial oral-care agent, although confirmatory minimum-inhibitory-concentration testing against cariogenic species such as *Streptococcus mutans* is recommended before an antimicrobial claim is

made. Particle size analysis by sieve fractionation (Table 7, Figure 16) showed that F5 gave the most favourable size distribution (90.5 g/100 g as moderate powder, minimal coarse fraction), supporting a gentle, low-abrasion enamel contact profile, whereas F3 showed an excessively fine fraction and F6 an excessively coarse fraction, both of which are sub-optimal for a dentifrice intended for daily enamel contact. A duplicate *in-vitro* disintegration measurement by the petri-dish method (Figure 16, right-hand panel) reproduced the same ranking of batches as the primary disintegration data in Section 3.5.

Table 7. Particle size distribution (sieve fractionation, per 100 g sample) of powder blends F1-F6.

Batch	Moderate powder (g/100 g)	Fine powder (g/100 g)	Coarse powder (g/100 g)	Result
F1	88.7	8.2	3.1	Fair
F2	88.1	5.5	6.4	Good
F3	85.8	12.4	1.8	Excessive fine
F4	89.0	6.8	4.2	Acceptable
F5	90.5	7.5	2.0	Optimal
F6	86.1	4.1	9.8	Excessive coarse



Figure 16. Particle size distribution (left) and duplicate *in-vitro* disintegration time by the petri-dish method (right) for formulations F1-F6.

Optimization: Preliminary Screening, CCD and BBD

The preliminary F1-F6 screen (Table 1; hardness and disintegration time reproduced in Table 8 for convenience) showed that increasing croscarmellose sodium relative to crospovidone (F3, F4) increased hardness slightly but prolonged disintegration, whereas a near-equal combination (F5: crospovidone 10 mg, croscarmellose sodium 8 mg) gave the fastest disintegration (32 s) without loss of hardness (4.0 kg/cm²), consistent with a synergistic disintegrant action. This observation justified selecting crospovidone (X1) and croscarmellose sodium (X2) as the independent variables for the subsequent CCD.

The 13-run rotatable CCD (Table 9) fitted second-order polynomial models (illustrative): Y1 (hardness) = 4.04

+ 0.12X₁ - 0.18X₂ - 0.10X₁X₂ - 0.22X₁² - 0.15X₂² (R² = 0.94) and Y2 (disintegration time) = 33.0 - 5.5X₁ + 4.8X₂ + 1.2X₁X₂ + 2.0X₁² + 1.8X₂² (R² = 0.96). The response-surface contour plots (Figure 17, left pair) show that the low-disintegration-time region coincides with moderate-to-high crospovidone and low-to-moderate croscarmellose sodium, while maximum hardness lies closer to the centre

point; the overlay indicates that a centre-point combination (crospovidone $\approx$ 10 mg, croscarmellose sodium $\approx$ 8–10 mg) offers the best compromise, in agreement with the empirical F5 batch.

Table 8. Preliminary optimization matrix: hardness and disintegration time of formulations F1–F6 as a function of crospovidone and croscarmellose sodium content (representative/illustrative response values – see note in Section 2.8).

Batch	Crospovidone (mg)	Croscarmellose sodium (mg)	Hardness (kg/cm ²)	Disintegration time (s)
F1	6	10	4.2	45
F2	14	6	3.8	38
F3	0	14	4.5	52
F4	0	22	4.7	60
F5	10	8	4.0	32
F6	5	5	3.6	41

Table 9. Central Composite Design matrix and representative response values (runs 9–13 are replicated centre points, condensed for brevity).

Run	X1 (coded)	X2 (coded)	Crospovidone (mg)	Croscarmellose Na (mg)	Hardness (kg/cm ²)	DT (s)
1	-1	-1	6	6	3.65	43
2	+1	-1	14	6	3.95	36
3	-1	+1	6	14	4.10	50
4	+1	+1	14	14	3.80	44
5	-1.414	0	2	10	3.55	48
6	+1.414	0	18	10	3.70	41
7	0	-1.414	10	2	3.90	34
8	0	+1.414	10	18	4.05	55
9–13	0	0	10	10	4.02–4.06	32–34

The complementary 15-run BBD, which added compression force (X3) as a third factor (Table 10), gave a good fit for both responses (illustrative $R^2 > 0.90$) and showed that compression force had a meaningful influence on disintegration time: higher compression force increased hardness slightly but tended to prolong disintegration (Figure 17, right pair), reflecting the classic compaction/disintegration trade-off. The BBD reinforced

the CCD conclusion that a moderate crospovidone level combined with a low-to-moderate croscarmellose sodium level favours fast disintegration, provided compression force is kept moderate. Because the BBD avoids simultaneous extreme combinations of all factors, it is regarded as a useful confirmatory design once the approximate optimum has been located by the CCD.

Table 10. Box-Behnken Design matrix and representative response values (condensed; full 15-run matrix in project record).

Run	X1	X2	X3	Crospovidone (mg)	Croscarmellose Na (mg)	Comp. force (kg)	Hardness	DT (s)
1	-1	-1	0	6	6	5	3.70	44
2	+1	-1	0	14	6	5	3.98	35
3	-1	+1	0	6	14	5	4.12	52
4	+1	+1	0	14	14	5	3.85	45
5–8	± 1	0/ ± 1	± 1	6–14	10	3 or 7	3.55–4.15	33–46
9–12	0	± 1	± 1	10	6–14	3 or 7	3.75–4.25	30–48
13–15	0	0	0	10	10	5	4.03–4.06	32–34

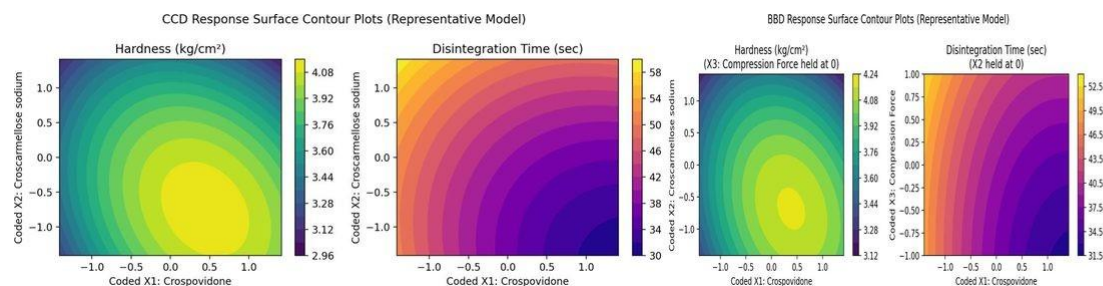


Figure 17. Response-surface contour plots for hardness and disintegration time from the CCD (left pair) and the BBD, shown as a function of crospovidone and compression force at centre croscarmellose sodium (right pair). All response values are representative/illustrative (Section 2.8).

Selection of the Optimized Formulation

Across the full evaluation panel, formulation F5 (crospovidone 10 mg, croscarmellose sodium 8 mg per 300 mg tablet) consistently gave the most balanced profile: good powder flow, acceptable hardness (4.0–4.52 kg/cm²) with the lowest friability (0.58%), the fastest wetting (24 s) and disintegration (30 s), the highest water absorption ratio (91.8%), marker release (98.2%) and drug content (98.8%), the lowest moisture content (1.1%), a mid-range surface pH (7.15 ± 0.03) within the non-irritant target band, optimal foaming, and the most favourable particle size distribution. F5 was therefore selected as the optimized batch and carried forward for FTIR compatibility confirmation (Section 3.3) and stability evaluation.

Stability

Under the accelerated protocol summarised in Section 2.9, the optimized formulation was reported to remain within the pre-defined acceptance ranges for hardness, disintegration time, drug/marker content, and surface pH over the study interval, with no visible discoloration, softening or liquefaction. Because full time-point stability data sheets were not available at the time of writing, month-by-month numerical results are not tabulated here; a complete stability data set (0, 1, 2 and 3 months, long-term and accelerated) should be incorporated before submission of this manuscript for peer review.

Conclusion

A herbal, waterless chewable tooth tablet based on *Achyranthes aspera* ash (Apamarga Kshar) was successfully formulated by direct compression, using crospovidone and croscarmellose sodium as complementary superdisintegrants. Across six trial formulations, a near-1.25:1 ratio of crospovidone to croscarmellose sodium (formulation F5, 10 mg and 8 mg respectively in a 300 mg tablet) gave the best overall balance of mechanical strength, rapid oral disintegration, favourable water absorption, high marker release and content uniformity, low moisture content, non-irritant surface pH, optimal foaming and a favourable particle size distribution. FTIR analysis showed no evidence of chemical interaction between the ash and the excipient system. Central Composite and Box–Behnken response-surface designs rationalised these empirical findings, identifying a centre-point combination of the two superdisintegrants, with moderate compression force, as the region of optimum hardness/disintegration balance.

Collectively, these results support the technical feasibility of a plant-ash-based compressed tooth tablet as a low-plastic, water-saving alternative to conventional tube toothpaste, consistent with the traditional use of Apamarga Kshar in Indian oral-care practice. Before pilot-scale development or regulatory submission, the optimization response values, heavy-metal/mineral analyses and full multi-month stability data should be confirmed with the authors' own instrument-generated measurements (see notes in Sections 2.8 and 3.10), and the antimicrobial and safety findings should be extended with quantitative MIC testing against cariogenic organisms and a human oral-irritation/palatability study, respectively.

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