Herbal Antidiabetic Chocolate: A Review of Plant Extracts, Formulation Strategies and Therapeutic Potential

Mr. Sagar Baliram Panchal[1], Dr. Kavaljit Satish Birajdar[2], Mr. Dasrao Ashok Patil[3]
[1,2,3,4]*Dept. of Pharmaceutics, BSS's Tatyaraoji More College of Pharmacy, Omerga*
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Abstract—**The global escalation of diabetes mellitus has necessitated creative, patient-centered therapeutic strategies beyond conventional pharmacotherapy. Among emerging nutraceutical platforms, herbal medicated chocolate has attracted considerable attention as a confectionery-based dosage form combining palatability with multitargeted pharmacological activity. This review systematically examines the scientific evidence underpinning chocolate as a nutraceutical carrier, evaluates the antidiabetic pharmacology of four widely studied medicinal plants — Psidium guajava, Gymnema sylvestre, Trigonella foenum-graecum, and Cinnamomum verum — and critically analyses the formulation strategies, physicochemical characterisation tools, and in-vitro biological evaluation models reported in published herbal chocolate studies. Special attention is given to the rationale for stevia-based sugar-free design, polyherbal synergism, and enzyme inhibition as a mechanistic validation endpoint. The existing literature consistently reports that such formulations achieve acceptable organoleptic and physicochemical attributes alongside significant alpha-amylase and alpha-glucosidase inhibitory activity. Challenges including thermal instability, limited bioavailability data, and absence of clinical evidence are highlighted, and future research directions are proposed.**

Index Terms—**Antidiabetic nutraceutical, confectionery drug delivery, enzyme inhibition, functional chocolate, Gymnema sylvestre, herbal formulation, Psidium guajava, polyherbal synergy, stevia, sugar-free chocolate.**

I. INTRODUCTION

Diabetes mellitus ranks among the most pressing non-communicable disease challenges of the twenty-first century. The International Diabetes Federation estimated 537 million adults living with diabetes globally in 2021, a figure projected to surpass 780 million by 2045, with low- and middle-income countries bearing a disproportionate burden [1]. India alone harbours approximately 74 million diabetic adults, placing it among the highest-burden nations worldwide [2]. The chronic, progressive nature of the disease, combined with the lifelong requirement for pharmacotherapy, places immense psychological and economic pressure on patients and healthcare systems. Despite an expanding pharmacological armamentarium — from metformin and GLP-1 receptor agonists to SGLT-2 inhibitors — adherence to long-term antidiabetic regimens remains poor. Systematic reviews report medication adherence rates as low as 36–93% across different diabetic populations, with complex regimens, adverse effects, and poor palatability cited as key barriers [3]. This adherence gap translates directly into suboptimal glycaemic control and accelerated progression to microvascular and macrovascular complications.

The convergence of traditional medicine and food science has generated significant interest in nutraceuticals — food-derived products providing health benefits beyond basic nutrition — as complementary adjuncts to standard care. Within this space, herbal medicated chocolates have emerged as a novel and scientifically credible strategy: they leverage the universal palatability of chocolate as a vehicle for delivering bioactive phytochemicals with antidiabetic properties [4]. This review consolidates and critically appraises published evidence on the design, formulation, and evaluation of herbal sugar-free antidiabetic chocolates, with emphasis on the pharmacological basis for plant selection, formulation science, and validation models used to substantiate therapeutic activity.

II. DIABETES MELLITUS: EPIDEMIOLOGY AND PATHOPHYSIOLOGICAL BASIS FOR NUTRACEUTICAL INTERVENTION

Type 2 diabetes mellitus accounts for over 90% of all diabetes cases and is characterised pathophysiologically by a dual defect: progressive peripheral insulin resistance and declining pancreatic beta-cell secretory capacity [5]. Postprandial glucose excursions — driven by rapid digestion and absorption of dietary carbohydrates — have been independently associated with increased cardiovascular risk, oxidative stress, and micro/macrovascular complications, even in patients with acceptable HbA1c levels [6].

The carbohydrate hydrolysis cascade begins with alpha-amylase cleaving starch into oligosaccharides, followed by brush-border alpha-glucosidase converting these into absorbable glucose monomers. Inhibiting these two enzymes is a physiologically rational strategy for blunting postprandial glucose spikes — the mechanism exploited by acarbose and, as reviewed herein, by several dietary phytochemicals present in antidiabetic herbal chocolates [7]. A second major pathophysiological driver of diabetic complications is chronic oxidative stress, which herbal polyphenols and flavonoids can address through direct free-radical scavenging and Nrf2 pathway upregulation [8].

III. CHOCOLATE AS A NUTRACEUTICAL DELIVERY PLATFORM

Chocolate's suitability as a drug delivery carrier rests on a convergence of technological, sensory, and pharmacological attributes. The fat-continuous matrix of dark chocolate — composed predominantly of cocoa butter with a melting range of 32–36°C — provides a thermoplastic solid at ambient temperature that transitions to a fluid at body temperature, enabling efficient incorporation of hydrophilic herbal extracts within the lipophilic matrix [9]. The pronounced cocoa flavour profile effectively masks the inherent bitterness, astringency, and earthy aftertaste of plant extracts that deter patients from accepting herbal medicines in conventional dosage forms [10].

Cocoa itself contributes pharmacological value beyond its carrier role. Dark chocolate is one of the richest dietary sources of flavan-3-ols (epicatechin, catechin) and procyanidins. Clinical meta-analyses confirm that cocoa flavanol consumption is associated with statistically significant reductions in fasting insulin, HOMA-IR index, and blood pressure, and improvements in endothelial function [11]. The practical advantages include no water required for administration, easy portion-controlled unit dosing, and intrinsic appeal to pediatric and elderly populations in whom conventional dosage form adherence is poor [12].

IV. RATIONALE FOR SUGAR-FREE DESIGN: STEVIA AND GLYCAEMIC SAFETY

A fundamental paradox in deploying conventional chocolate as a diabetic nutraceutical is its high sucrose content. Stevia rebaudiana Bertoni (Asteraceae) resolves this: its steviol glycosides — principally stevioside and rebaudioside A — are 200–350 times sweeter than sucrose yet contribute negligible caloric value [13]. Multiple randomised controlled trials demonstrate that stevia consumption does not stimulate postprandial insulin secretion, does not raise blood glucose, and may modestly reduce it through GLP-1 and PYY hormone potentiation [14]. Steviol glycosides are thermostable to approximately 120°C and pH-stable across the range 2–10, surviving the mild heating required for chocolate manufacture without degradation [15].

Oliveira et al. (2022) confirmed in human volunteers that stevia-sweetened dark chocolate produced a significantly lower postprandial glucose area under the curve compared to sucrose-sweetened equivalents, providing direct clinical validation for the sugar-free design strategy [16]. Other polyol sweeteners (sorbitol, xylitol, erythritol) and prebiotic fibres (inulin) have also been explored as bulking agents in some formulations, though polyols carry laxative risk at high doses and require careful dose management [17].

V. PHARMACOLOGICAL REVIEW OF ANTIDIABETIC HERBAL CONSTITUENTS

A. Psidium guajava Linn. (Guava Leaves)

Guava leaves are among the most extensively investigated herbal antidiabetic materials in chocolate formulations. Antidiabetic activity has been attributed primarily to quercetin and guaijaverin (flavonoids), gallotannins, and polyphenolic acids. The predominant mechanism is non-competitive inhibition of intestinal alpha-glucosidase, effectively reducing the rate of disaccharide hydrolysis at the brush border [18]. Deguchi and Miyazaki (2010) demonstrated that guava leaf tea administration produced statistically significant attenuation of postprandial blood glucose sustained across a 120-minute observation window in both healthy and T2DM subjects [19]. Beyond glycaemic control, guava leaf flavonoids demonstrate antioxidant activity, anti-inflammatory effects via COX-2 inhibition, and antimicrobial activity against common opportunistic pathogens relevant to immunocompromised diabetic patients [20].

B. Gymnema sylvestre R.Br. (Gurmar)

Gymnema sylvestre holds a distinguished position in Ayurvedic medicine as the quintessential sugar-destroyer. Its leaves contain gymnemic acids (triterpenoid saponins) that temporarily abolish sweet taste perception by occupying taste receptors — a property useful in reducing dietary sugar craving in diabetic patients [21]. At the cellular level, gymnemic acids stimulate regeneration of islet beta-cells, distinguishing Gymnema from most synthetic antidiabetics which merely stimulate existing beta-cells. Clinical trials by Shanmugasundaram et al. demonstrated significant reductions in fasting blood glucose (17–24%) and HbA1c over 18-month supplementation periods in T2DM patients, with some patients able to reduce sulfonylurea dosage [22].

C. Trigonella foenum-graecum Linn. (Fenugreek)

Fenugreek seeds exert antidiabetic effects through three distinct mechanisms: galactomannan (45–60% of dry weight) physically slows gastric emptying and carbohydrate absorption; the alkaloid trigonelline acts as a DPP-4 inhibitor potentiating GLP-1-mediated insulin secretion; and diosgenin improves peripheral insulin receptor sensitivity through PPAR-gamma activation [23]. Meta-analyses of human clinical trials confirm statistically significant reductions in fasting blood glucose, postprandial glucose, and HbA1c with fenugreek supplementation at standard doses [24].

D. Cinnamomum verum J.Presl (Cinnamon)

Cinnamon's antidiabetic activity originates from water-soluble type-A procyanidins and methylhydroxychalcone polymers that activate insulin receptor tyrosine kinase and inhibit PTP-1B, effectively potentiating insulin signalling at the receptor level [25]. It is critical to specify Cinnamomum verum (Ceylon cinnamon) rather than C. cassia (Chinese cinnamon): cassia contains significantly higher levels of hepatotoxic coumarin, making C. verum the only safe choice for a product intended for long-term regular consumption [26]. A Cochrane-affiliated systematic review of 16 RCTs reported modest but statistically significant reductions in fasting blood glucose and total cholesterol with cinnamon supplementation [27].

VI. FORMULATION PROCESS: OVERVIEW AND FLOWCHART

The preparation of herbal sugar-free antidiabetic chocolate follows a sequential six-stage process integrating pharmacognostical, pharmaceutical, physicochemical, and biological evaluation steps. Figure 1 illustrates the complete formulation workflow from plant extraction to antidiabetic activity validation.

Fig. 1: Flowchart of Herbal Antidiabetic Chocolate Formulation Process

Stage 1 (Plant Extraction) involves the collection, authentication, shade-drying, and coarse powdering of medicinal plant materials. Stage 2 (Extract Preparation) employs the aqueous decoction method — boiling powdered plant materials at 90–100°C for 30–45 minutes in distilled water, followed by filtration through muslin cloth and Whatman No. 1 filter paper, and storage of concentrated filtrate at 4°C. Stage 3 (Chocolate Formulation) consists of melting cocoa butter at 40–50°C, incorporating cocoa powder with continuous stirring, adding stevia and herbal extracts sequentially with homogenisation, degassing, pouring into pre-lubricated moulds, and controlled cooling until solidification. Stages 4–6 constitute the evaluation framework described in the following section.

VII. COMPARATIVE REVIEW OF PUBLISHED HERBAL CHOCOLATE FORMULATIONS

The past five years have witnessed a marked increase in publications describing herbal antidiabetic chocolates. Table I summarises the key characteristics of representative published studies, enabling critical comparison of plant combinations, sweeteners, and evaluation outcomes.

Table I: Comparative Summary of Published Herbal Antidiabetic Chocolate Formulations

Author (Year)	Herbal Agents	Base / Sweetener	Key Evaluation	Notable Finding
Gawande et al. (2025)	Fenugreek, Guava, Jamun	Cocoa butter / Stevia	pH, WT, α-glucosidase	Good stability; enzyme inhibition
Sagare et al. (2025)	Gymnema, Fenugreek, Bitter gourd, Cinnamon	Cocoa base / Stevia	α-Amylase & α-glucosidase	Dual-enzyme inhibition vs acarbose
Jogdand et al. (2025)	Guava leaf	Cocoa butter / Stevia	Hardness, Appearance, Stability	Stable at RT; good texture
Mahale et al. (2025)	Guava + Aegle marmelos	Dark choc / Stevia	Organoleptic, pH, Blooming	No blooming; good palatability
Gagare et al. (2025)	Syzygium cumini	Cocoa butter / Stevia	Antioxidant, organoleptic	Strong antioxidant; pleasant taste
Borawake et al. (2024)	Tridax procumbens	Cocoa base / Stevia	Physicochemical, stability	Effective bitter taste masking
Lode et al. (2023)	Trigonella foenum-graecum	Cocoa butter / Sugar-free	Hardness, WT, organoleptic	Satisfactory WT; fenugreek masked
Ghuge et al. (2023)	Guava leaf + Mulberry	Cocoa / Stevia	Antidiabetic, antioxidant	Synergistic dual activity
Oliveira et al. (2022)	— (comparative study)	Dark choc / Stevia+erythritol	Postprandial glucose (human trial)	Lower glucose AUC vs sucrose-choc

Analysis of Table I reveals consistent trends: stevia is universally preferred as the sweetener of choice; guava leaf extract appears in the highest number of independent publications reflecting its reliable alpha-glucosidase inhibitory potency and cocoa-compatibility; and in-vitro enzyme inhibition is the predominant biological endpoint. The sole published human clinical study (Oliveira et al., 2022) underscores the critical gap in clinical evidence and the pressing need for randomised controlled trials in this field.

VIII. EVALUATION APPROACHES IN HERBAL CHOCOLATE RESEARCH

A. Physicochemical and Organoleptic Characterisation

Standard physicochemical parameters reported across publications include pH (1 g dispersed in 50 mL phosphate buffer pH 6.8), melting point by water bath method, weight variation across 10 units, thickness by

Vernier callipers, and viscosity of the molten mass by rotational viscometry. Published studies report pH values of 5.8–6.8, melting points of 32–40°C for conventional bases, and weight variation generally within ±5% [28,29,30]. Organoleptic evaluation by a semi-trained sensory panel on a hedonic scale confirms that the cocoa matrix successfully masks herbal bitterness at therapeutically relevant concentrations.

B. Stability and Blooming Assessment

Stability is assessed under ICH-aligned conditions (25°C/60% RH; 30°C/65% RH; 40°C/75% RH) at 0, 7, 14, and 30-day intervals, monitoring appearance, texture, odour, pH, and bloom. Herbal chocolates remain physically stable at or below room temperature across the observation periods studied, while elevated temperature causes progressive softening, phase separation, and fat or sugar bloom [33,35]. Long-term stability data (6–24 months) are conspicuously absent from current publications — a regulatory prerequisite for any commercial product.

C. In-Vitro Enzyme Inhibition Assays

Alpha-amylase (DNS colorimetric at 540 nm) and alpha-glucosidase (pNPG substrate at 405 nm) inhibition assays are the de facto standard for biological validation. Acarbose is the universally employed positive control. Published herbal chocolate extracts consistently demonstrate IC50 values 1.5–5-fold higher than acarbose, indicating meaningful but comparatively lower potency. Table II presents comparative enzyme inhibition data from representative studies.

Table II: Comparative In-Vitro Enzyme Inhibition (% Inhibition at 100 µg/mL) from Published Studies

Study	α-Amylase Inhibition (%)	α-Glucosidase Inhibition (%)	Herbal Combination
Sagare et al. (2025)	67.8 ± 0.6	63.2 ± 0.5	Gymnema + Fenugreek + Bitter gourd + Cinnamon
Gawande et al. (2025)	61.4 ± 0.7	58.9 ± 0.6	Fenugreek + Guava leaf + Jamun seed
Kape Omkar Anil (2025)	58.7 ± 0.5	55.3 ± 0.4	Guava leaf + Black sesame
Nandeshwar et al.	63.1 ± 0.8	60.5 ± 0.7	Syzygium cumini + Psidium guajava + Morus alba
Acarbose (Standard)	80–85 (reference)	78–83 (reference)	Synthetic alpha-glucosidase inhibitor

IX. POLYHERBAL SYNERGISM AND THERAPEUTIC RATIONALE

The simultaneous use of multiple herbal agents targets several complementary pathways in T2DM pathophysiology. Guava leaf inhibits intestinal alpha-glucosidase; Gymnema stimulates beta-cell regeneration and suppresses glucose transport; fenugreek physically slows absorption and inhibits DPP-4; cinnamon sensitises insulin receptors and inhibits PTP-1B. The intrinsic cocoa flavanols provide a fifth vector — improving insulin sensitivity and endothelial function through nitric oxide pathway activation [11]. This multi-targeted profile mirrors the rational polypharmacy principle: four agents producing additive or synergistic effects at lower individual doses than high-dose monotherapy [36].

Formal synergy quantification using Chou and Talalay's combination index method has not yet been applied to herbal chocolate combinations and represents an important methodological advance for future studies. Published polyherbal formulations consistently outperform single-herb chocolates in enzyme inhibition assays, providing empirical — if not yet formally quantified — evidence of synergistic interaction [37].

X. CHALLENGES, LIMITATIONS, AND FUTURE RESEARCH DIRECTIONS

Bioavailability and Bioaccessibility: Demonstrating in-vitro enzyme inhibition is necessary but not sufficient. The extent to which phytochemicals are released from the chocolate matrix during digestion, absorbed across the intestinal epithelium, and escape first-pass hepatic metabolism remains unstudied. The lipophilic cocoa butter matrix may both enhance absorption of lipid-soluble phytochemicals and retard dissolution of hydrophilic extracts — effects requiring systematic bioaccessibility studies using validated in-vitro digestion models (INFOGEST) or Caco-2 cell assays [38].

Standardisation: Most published studies use unstandardised laboratory-prepared extracts, making inter-study comparisons unreliable and commercial scale-up impossible. Future work must adopt HPLC-validated methods to quantify key markers — quercetin in guava, gymnemic acid A in Gymnema, trigonelline in fenugreek, cinnamaldehyde in cinnamon — and establish batch acceptance criteria [39]. Clinical Validation: The current evidence base rests almost entirely on in-vitro data. Randomised controlled trials evaluating HbA1c, fasting blood glucose, and postprandial glucose over 12–24 weeks are the critical evidence required for clinical adoption and regulatory endorsement.

Regulatory Framework: In India, such products occupy a grey zone between FSSAI functional foods, AYUSH traditional formulations, and CDSCO medicinal products depending on claimed health benefits and dosing recommendations — a challenge requiring early regulatory engagement for any product seeking commercial development.

XI. CONCLUSION

Herbal antidiabetic chocolate represents a scientifically grounded and practically innovative nutraceutical strategy for complementary diabetes management. The convergence of a pharmacologically active dark chocolate base, a safe non-caloric sweetener (stevia), and a rationally selected polyherbal combination targeting multiple mechanistic nodes in glycaemic dysregulation creates a formulation with genuine therapeutic promise and substantial patient acceptability advantages over conventional herbal preparations.

The existing literature, while encouraging, is characterised by significant methodological heterogeneity, reliance on in-vitro validation, and a conspicuous absence of pharmacokinetic and clinical data. Advancing this field to clinical relevance requires standardised herbal extracts, systematic in-vivo pharmacological studies, formal synergy characterisation, long-term stability data under ICH conditions, and well-powered randomised clinical trials. Investment in these research priorities has the potential to position herbal chocolate as a credible, evidence-based nutraceutical option for the rapidly growing global diabetic population.

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