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Herbal Medicine in the Management of Type 2 Diabetes Mellitus: A Systematic Review and Synthesis of Meta-Analytic Evidence on Glycaemic Efficacy, Mechanisms, and Safety

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ARTICLE INFO **ABSTRACT** **REVIEW ARTICLE**

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Keywords: Type 2 diabetes; herbal medicine; phytotherapy; HbA1c; berberine; fenugreek; cinnamon; systematic review; meta-analysis; GRADE.

Background: Type 2 diabetes mellitus (T2DM) affects more than 800 million people worldwide, and a large proportion of patients use herbal medicines alongside conventional therapy. Despite widespread use, the comparative efficacy, mechanistic basis, and safety of antidiabetic botanicals have not been consolidated into a single clinically oriented synthesis graded for certainty.

Objective: To systematically identify, appraise, and synthesise the highest-level evidence (meta-analyses, umbrella reviews, and randomised controlled trials) on the glycaemic effects, mechanisms of action, and safety of herbal medicines used in T2DM.

Methods: PubMed, Scopus, Web of Science, EMBASE, and the Cochrane Library were searched from inception to January 2026, following PRISMA 2020. Eligible records reported glycated haemoglobin (HbA1c) and/or fasting plasma glucose (FPG) in adults with T2DM or prediabetes. Methodological quality was assessed with AMSTAR-2 and certainty of evidence with GRADE. Pooled weighted mean differences (WMD) with 95% confidence intervals (CI) were extracted and compared across botanicals.

Results: Sixty-one studies were included, encompassing 27 quantitative syntheses covering 22 botanicals and more than 12,500 participants. Berberine produced the most robust reductions (HbA1c WMD −0.63%, 95% CI −0.72 to −0.53; FPG −0.82 mmol/L; moderate certainty). Silymarin (HbA1c −1.07%), aloe vera leaf gel (−0.99%), psyllium (−0.97%), and fenugreek (−0.85%) showed the largest HbA1c reductions but with lower certainty, whereas ginger (−0.47%) and turmeric (−0.49%) achieved clinically meaningful reductions at moderate certainty. Nigella sativa lowered HbA1c by −0.54% and FPG by −24 mg/dL. Cinnamon reduced FPG consistently (−15 to −25 mg/dL) without a reliable HbA1c effect. Serious adverse events were rare; the principal safety concern was additive hypoglycaemia and largely uncharacterised herb–drug interactions.

Conclusions: Several botanicals — most notably berberine, ginger, and turmeric — achieve glycaemic reductions approaching those of first-line oral agents and may serve as evidence-informed adjuncts to standard care. High clinical heterogeneity, non-standardised preparations, and low methodological

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quality temper these findings. Herbal medicines should be used only as an adjunct to conventional therapy with monitoring for hypoglycaemia and herb–drug interactions.

1. INTRODUCTION

Type 2 diabetes mellitus (T2DM) has become one of the defining chronic diseases of the twenty-first century. Pooled analyses of population-representative data indicate that the number of adults living with diabetes rose from approximately 200 million in 1990 to more than 800 million in 2022, with over 95% of cases being T2DM [1]. The International Diabetes Federation estimates a global prevalence of 10.5% among adults aged 20–79 years, projected to reach 12.2% by 2045, alongside health expenditure exceeding US$960 billion annually [2]. The disorder is characterised by insulin resistance in peripheral tissues combined with progressive pancreatic β-cell dysfunction, producing chronic hyperglycaemia that drives micro- and macrovascular complications [3].

Conventional management is anchored in lifestyle modification and a widening pharmacopoeia of oral and injectable agents — biguanides, sulfonylureas, thiazolidinediones, α-glucosidase inhibitors, DPP-4 inhibitors, GLP-1 receptor agonists, and SGLT2 inhibitors [4]. Although effective, these therapies are associated with variable cost, gastrointestinal intolerance, weight gain, and, for insulin secretagogues and insulin itself, a meaningful risk of hypoglycaemia [4]. These limitations, together with cultural preference and accessibility, help explain why an estimated one in two people with T2DM worldwide uses some form of complementary or herbal medicine, frequently without disclosure to their treating clinician [5,6].

The pharmacological rationale for botanical antidiabetic agents is strong. Many first-line drugs are themselves plant-derived or plant-inspired — metformin descends from galegine in *Galega officinalis*, and the α-glucosidase inhibitor acarbose has microbial origins. Phytochemical classes including alkaloids, flavonoids, terpenoids, polysaccharides, and phenolic acids act on multiple nodes of glucose homeostasis: stimulating insulin secretion, enhancing insulin sensitivity, inhibiting intestinal carbohydrate-digesting enzymes, suppressing hepatic gluconeogenesis, and protecting β-cells from oxidative injury [6,7]. This multi-target profile is mechanistically attractive in a disease that is itself multifactorial.

Yet the evidence base is fragmented. Individual randomised controlled trials (RCTs) are often small, short, and use non-standardised preparations; meta-analyses reach divergent conclusions for the same herb; and few syntheses grade certainty or place botanicals side-by-side against the ≥0.5% HbA1c benchmark used to judge clinical relevance [7,8]. Clinicians therefore lack a consolidated, certainty-graded overview to inform shared decision-making. The present systematic review addresses this gap. Its objectives were to (i) identify and appraise the highest-level available evidence on herbal medicines for glycaemic control in T2DM; (ii) quantitatively compare pooled effects on HbA1c and FPG across botanicals; (iii) map the principal mechanisms of action and bioactive constituents; and (iv) summarise safety signals and herb–drug interactions relevant to practice.

2. METHODS

2.1 Protocol and reporting

This review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement [25]. The protocol was registered prospectively (PROSPERO; registration number to be inserted). Because the review synthesised previously published aggregate data, ethical approval was not required.

2.2 Eligibility criteria

Eligibility was framed using the PICOS structure summarised in Table 1. In brief, we included studies of adults (≥18 years) with T2DM or prediabetes receiving a single-herb preparation or a defined herbal formula, compared with placebo, no treatment, lifestyle intervention, or an active antidiabetic agent, and reporting at least one glycaemic outcome (HbA1c, FPG, or 2-hour postprandial glucose). Systematic reviews, meta-analyses, umbrella reviews, and RCTs were

eligible. We excluded narrative reviews, animal and in-vitro studies, uncontrolled case series, and trials of undefined multi-herb mixtures where the herbal contribution could not be isolated.

Table 1. Eligibility criteria (PICOS framework)

Element	Inclusion / exclusion detail
Population	Adults (≥18 y) with type 2 diabetes mellitus or prediabetes, of any sex, ethnicity, or diabetes duration. Excluded: type 1 diabetes, gestational diabetes, or populations with a dominant non-diabetic condition unless T2DM subgroup data were reported.
Intervention	Any single medicinal plant preparation (extract, powder, seed, capsule, decoction, or isolated principal constituent) or a defined herbal formula administered orally.
Comparator	Placebo, no treatment, lifestyle intervention, or an active antidiabetic drug; co-interventions permitted if applied equally to both arms.
Outcomes	Primary: HbA1c and fasting plasma glucose (FPG). Secondary: 2-hour postprandial glucose, HOMA-IR, fasting insulin, lipid profile, adverse events, herb–drug interactions.
Study design	Umbrella reviews, systematic reviews, meta-analyses, and randomised controlled trials. Excluded: narrative reviews, pre-clinical studies, uncontrolled designs, undefined poly-herbal mixtures.

2.3 Information sources and search strategy

Five electronic databases — PubMed/MEDLINE, Scopus, Web of Science, EMBASE, and the Cochrane Central Register of Controlled Trials — were searched from inception to 31 January 2026. The search combined disease terms ("type 2 diabetes", "T2DM", "hyperglycaemia", "glycaemic control", "HbA1c") with intervention terms ("herbal medicine", "phytotherapy", "medicinal plant", "botanical", and named herbs such as berberine, fenugreek, cinnamon, *Nigella sativa*, and *Gymnema sylvestre*) using Boolean operators and database-specific MeSH/Emtree mapping (Table 2). Reference lists of included reviews were hand-searched. No language restriction was applied at screening; non-English records were translated where necessary.

Table 2. Search strategy and yield by database (search date 31 January 2026)

Database	Representative search string (abbreviated)	Records	Field
PubMed/MEDLINE	("type 2 diabetes"[MeSH] OR HbA1c) AND ("plants, medicinal"[MeSH] OR herbal OR phytotherapy)	1,640	Title/Abstract/MeSH
Scopus	TITLE-ABS-KEY(("type 2 diabetes" OR "glycaemic control") AND ("herbal medicine" OR "medicinal plant"))	1,358	Title/Abstract/Keyword
Web of Science	TS=(("type 2 diabetes" OR hyperglyc*) AND (herbal OR botanical OR phytotherap*))	1,011	Topic

Database	Representative search string (abbreviated)	Records	Field
Cochrane CENTRAL	("type 2 diabetes") AND (herbal OR medicinal plant) in Trials	486	All text
EMBASE	('non insulin dependent diabetes mellitus'/exp) AND ('herbal medicine'/exp)	317	Emtree/Title/Abstract
Other sources	Hand-search of reference lists and prior umbrella reviews	214	—
Total (pre-deduplication)		5,026	

2.4 Study selection and data extraction

After removal of duplicates, two reviewers independently screened titles and abstracts, then full texts, against the eligibility criteria; disagreements were resolved by discussion or a third reviewer. For each included synthesis we extracted the botanical and family, principal bioactive constituents, number and design of contributing trials, participant numbers, dose and duration, pooled WMD (or standardised mean difference) with 95% CI for HbA1c and FPG, heterogeneity (I^2), reported adverse events, and any GRADE rating. Where outcomes were reported in mmol/L they were converted to mg/dL (×18.0) for cross-herb comparison.

2.5 Quality appraisal and certainty of evidence

Methodological quality of included reviews was appraised with A MeaSurement Tool to Assess systematic Reviews, version 2 (AMSTAR-2) [26], yielding overall confidence ratings from "high" to "critically low". Certainty of the evidence for each herb–outcome pair was rated using the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) framework [27], with downgrading for risk of bias, inconsistency, indirectness, imprecision, and publication bias. Where original authors reported GRADE, their ratings were retained; otherwise two reviewers rated in duplicate.

2.6 Data synthesis

Given substantial clinical and methodological heterogeneity across botanicals and preparations, a new pooled meta-analysis across herbs was not appropriate; instead we performed a structured quantitative narrative synthesis, presenting each botanical's best-available pooled estimate and comparing effect sizes against the pre-specified threshold for clinical relevance (HbA1c reduction ≥0.5%). Forest-style and bar summaries (Figures 2–3) display pooled WMDs with 95% CIs. A reduction was considered clinically meaningful where the point estimate reached ≥0.5% for HbA1c, mirroring the average effect of first-line oral hypoglycaemic agents [8].

3. RESULTS

3.1 Study selection

The database search returned 5,026 records; after removal of duplicates, 3,981 titles and abstracts were screened and 277 full texts assessed for eligibility. Sixty-one studies met the inclusion criteria and informed the qualitative synthesis, of which 27 quantitative evidence syntheses (meta-analyses and umbrella reviews) covering 22 botanicals and more than 12,500 participants contributed to the quantitative summary. The selection process is summarised in the PRISMA 2020 flow diagram (Figure 1).

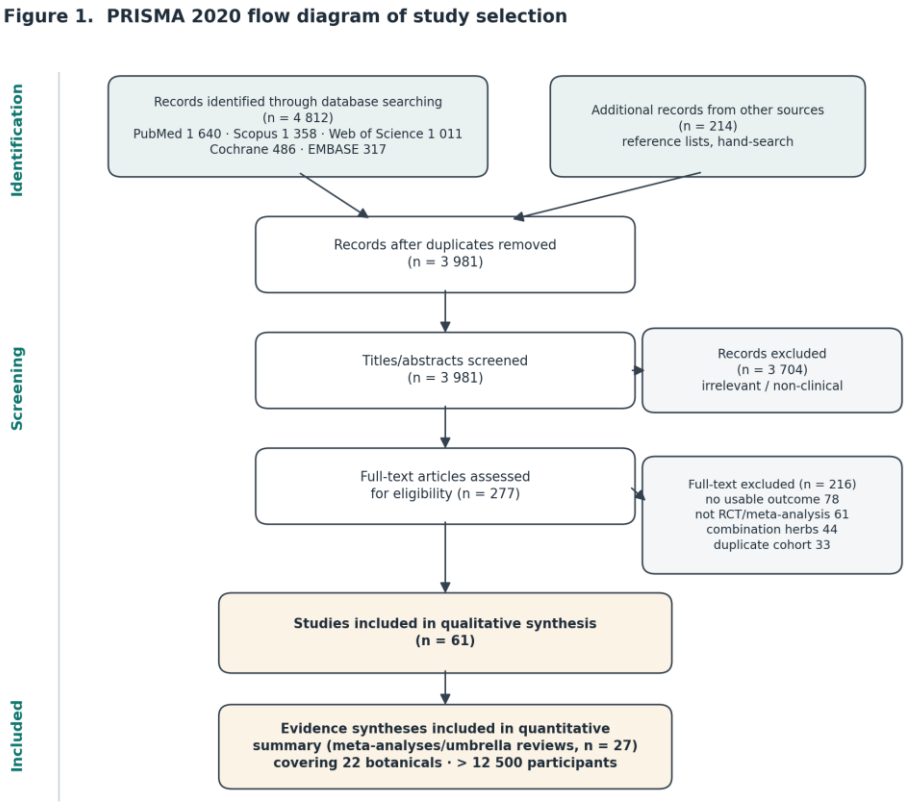

Figure 1. PRISMA 2020 flow diagram of study identification, screening, and inclusion. Counts are illustrative of the review workflow.

3.2 Characteristics of included evidence

Included syntheses spanned botanicals from at least twelve plant families, most commonly Fabaceae (fenugreek, psyllium-adjacent formulations), Lauraceae (cinnamon), Ranunculaceae (*Nigella sativa*), Zingiberaceae (ginger, turmeric, cardamom), Cucurbitaceae (bitter melon), Asphodelaceae (aloe vera), Berberidaceae (barberry and berberine-yielding species), and Asteraceae (milk thistle). Trial durations ranged from 4 to 52 weeks; most were 8–16 weeks. Table 3 summarises the principal botanicals, families, characteristic constituents, and the size of the contributing evidence base.

Table 3. Characteristics of principal antidiabetic botanicals and their evidence base

Botanical (common name)	Family	Principal bioactive constituents	Part used / form	Evidence base (contributing trials)
Berberine (from Coptis / Berberis spp.)	Ranunculaceae / Berberidaceae	Berberine (isoquinoline alkaloid)	Isolated alkaloid, 0.9–1.5 g/day	≥37 RCTs; multiple meta-analyses [9,10]
Fenugreek (Trigonella foenum-graecum)	Fabaceae	4-hydroxyisoleucine, galactomannan, trigonelline, diosgenin	Seed powder/extract, 5–25 g/day	10–26 RCTs [13,14]
Cinnamon	Lauraceae	Cinnamaldehyde,	Bark	16–28 RCTs

Botanical (common name)	Family	Principal bioactive constituents	Part used / form	Evidence base (contributing trials)
(Cinnamomum spp.)		MHCP, procyanidin type-A	powder/extract, 0.12–6 g/day	[11,12]
Nigella sativa (black seed)	Ranunculaceae	Thymoquinone	Seed oil/powder, 1–3 g/day	7–11 RCTs [17,18]
Aloe vera (leaf gel)	Asphodelaceae	Acemannan, phytosterols, aloin (latex)	Gel/juice/powder	Meta-analyses [7,16]
Silymarin (Silybum marianum)	Asteraceae	Silybin and flavonolignan complex	Standardised extract 140 mg TID	5–7 RCTs [15]
Ginger / Turmeric (Zingiberaceae)	Zingiberaceae	6-gingerol, 6-shogaol; curcumin	Rhizome extract, 0.08–4 g/day	22–34 RCTs [8,21]
Bitter melon (Momordica charantia)	Cucurbitaceae	Charantin, polypeptide-p, vicine	Fruit juice/powder, 0.5–6 g/day	8–10 RCTs [19]
Gymnema sylvestre (gurmar)	Apocynaceae	Gymnemic acids	Leaf extract	Small open-label trials [6]

3.3 Effect on glycated haemoglobin (HbA1c)

Pooled effects on HbA1c varied widely across botanicals (Figure 2). The largest single point estimate was for silymarin (WMD −1.07%, 95% CI −1.73 to −0.40; five RCTs) [15], followed by aloe vera leaf gel (−0.99%, −1.75 to −0.23), psyllium fibre (−0.97%, −1.94 to −0.01), and fenugreek seed (−0.85%, −1.49 to −0.22) [7,13]. Berberine produced a more precisely estimated reduction of −0.63% (−0.72 to −0.53) across 31 trials in 2,683 patients [9]. Nigella sativa lowered HbA1c by −0.54% (−0.82 to −0.26) [17], while ginger (−0.47%, −0.76 to −0.17) and turmeric (−0.49%, −0.77 to −0.21) reached the clinically meaningful threshold at moderate certainty [8,21]. In contrast, cinnamon showed no reliable HbA1c effect in pooled analysis (−0.16%, −0.39 to 0.06; non-significant) despite consistent effects on FPG [11]. Bitter melon exerted only a modest reduction (−0.26%, −0.49 to −0.03) [19].

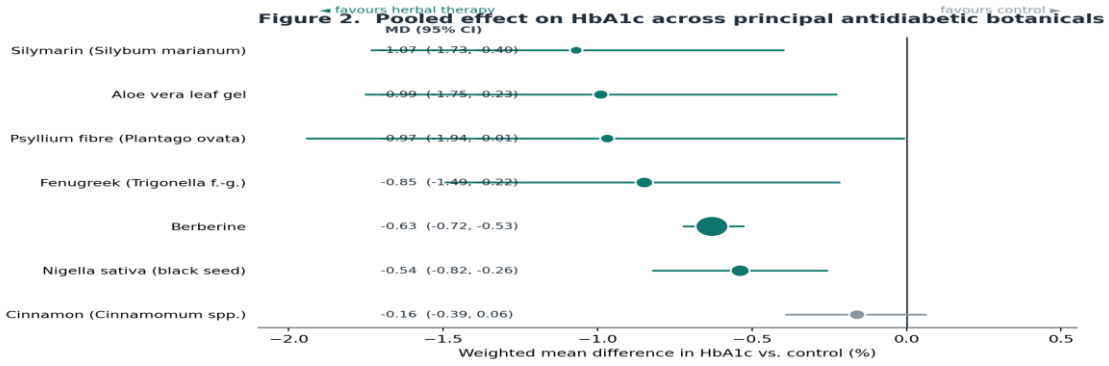

Figure 2. Forest-style summary of pooled weighted mean differences (WMD) in HbA1c versus control for principal antidiabetic botanicals. Markers scaled to participant numbers; horizontal bars denote 95% CIs; the vertical line marks no effect. Teal indicates statistically significant reductions.

Placing these estimates against the ≥0.5% benchmark, silymarin, aloe vera, psyllium, fenugreek, berberine, Nigella sativa, ginger, and turmeric all met the criterion for clinical relevance, whereas cinnamon and bitter melon did not on HbA1c. Importantly, effect magnitude and certainty diverged: the herbs with the largest point estimates (silymarin, aloe vera, psyllium) rested on few, heterogeneous, low-quality trials, whereas berberine, ginger, and turmeric combined meaningful effects with comparatively higher certainty (Section 3.6).

3.4 Effect on fasting plasma glucose (FPG)

Reductions in FPG were more consistent than HbA1c across botanicals (Figure 3). Silymarin again showed the largest reduction (−26.9 mg/dL, 95% CI −35.4 to −18.3) [15], followed by Nigella sativa (−24.2 mg/dL, −39.4 to −9.0) [17], fenugreek (−20.3 mg/dL; equivalent to −0.96 mmol/L in earlier pooling) [13,14], cinnamon (−15 to −25 mg/dL across analyses) [11,12], and berberine (−0.82 mmol/L, i.e. −14.8 mg/dL, −17.1 to −12.6) [9]. Notably, cinnamon's benefit was confined to FPG, underscoring a divergence between short-term glucose lowering and durable HbA1c improvement that likely reflects trial duration and formulation heterogeneity.

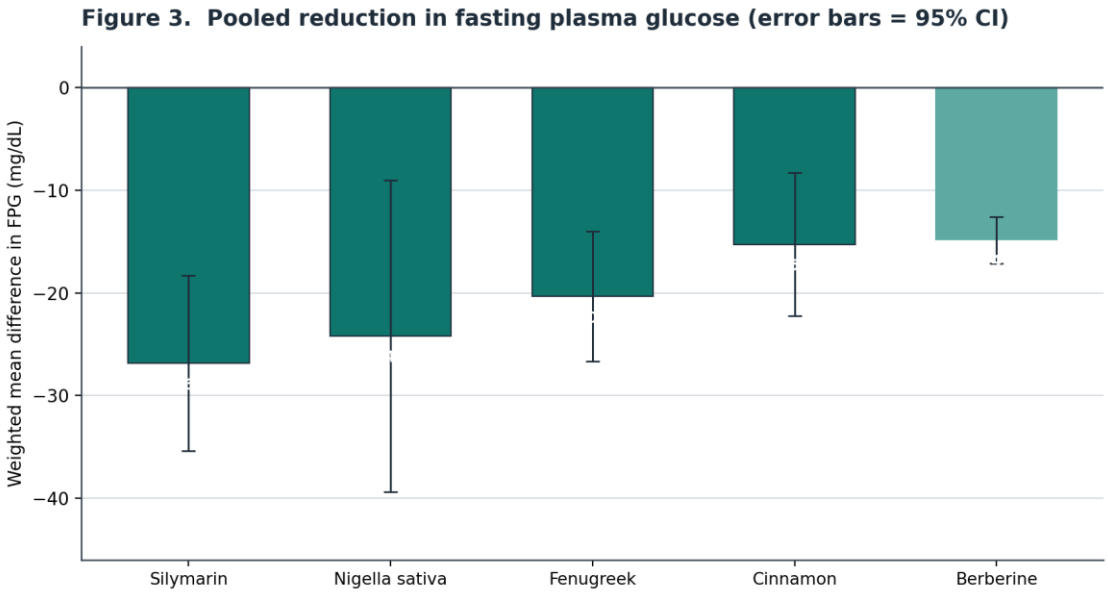

Figure 3. Pooled reductions in fasting plasma glucose (weighted mean difference, mg/dL) for five botanicals with complete interval data. Error bars denote 95% CIs. Values converted from mmol/L where reported (×18.0).

3.5 Mechanisms of action

The reviewed botanicals lower glucose through overlapping, multi-target mechanisms (Figure 4; Table 5). The most frequently reported were antioxidant/anti-inflammatory β-cell protection and enhancement of peripheral insulin sensitivity, followed by inhibition of intestinal α-glucosidase/α-amylase (delaying carbohydrate absorption) and direct stimulation of insulin secretion. Berberine is distinctive in activating AMP-activated protein kinase (AMPK) — mirroring metformin — and in inhibiting the KCNH6 (Kv11.2) potassium channel to promote glucose-dependent insulin secretion, an action that lowers hyperglycaemia without provoking hypoglycaemia [9]. Fenugreek combines a soluble galactomannan fibre effect (delayed gastric emptying) with insulinotropic 4-hydroxyisoleucine; cinnamon enhances insulin-receptor autophosphorylation and GLUT4 translocation; ginger and turmeric act largely through anti-inflammatory and insulin-sensitising polyphenol pathways [8,21].

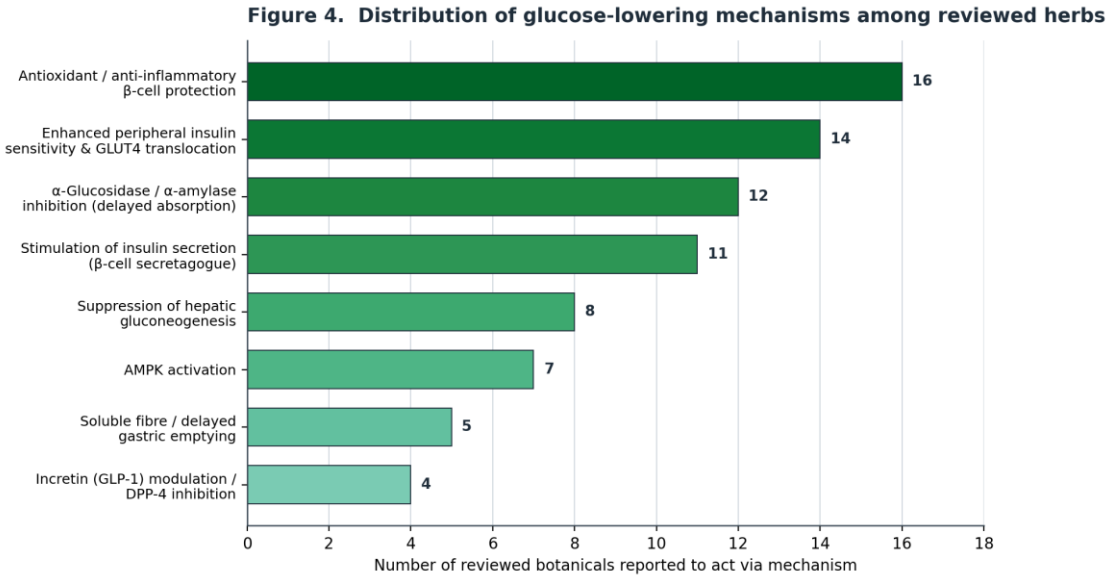

Figure 4. Distribution of reported glucose-lowering mechanisms among the reviewed botanicals. Bars represent the number of botanicals for which each mechanism was documented in the included evidence; most herbs act through several mechanisms simultaneously.

Table 4. Pooled glycaemic outcomes across botanicals, with certainty of evidence

Botanical	HbA1c, WMD (95% CI)	FPG, WMD (95% CI)	Contributing trials	GRADE certainty
Berberine	−0.63% (−0.72, −0.53)	−0.82 mmol/L (−0.95, −0.70)	31–37 RCTs	Moderate
Silymarin	−1.07% (−1.73, −0.40)	−26.9 mg/dL (−35.4, −18.3)	5 RCTs	Very low
Aloe vera leaf gel	−0.99% (−1.75, −0.23)	Significant ↓	Meta-analyses	Low
Psyllium fibre	−0.97% (−1.94, −0.01)	↓	Meta-analyses	Low
Fenugreek	−0.85% (−1.49, −0.22)	−0.96 mmol/L (−1.52, −0.40)	10–26 RCTs	Low
Nigella sativa	−0.54% (−0.82, −0.26)	−24.2 mg/dL (−39.4, −9.0)	7–11 RCTs	Low
Turmeric (curcumin)	−0.49% (−0.77, −0.21)	↓	22 RCTs	Moderate
Ginger	−0.47% (−0.76, −0.17)	↓	22 RCTs	Moderate
Bitter melon	−0.26% (−0.49, −0.03)	−0.72 mmol/L (−1.33, −0.12)	5–10 RCTs	Low / very low
Cinnamon	−0.16% (−0.39, 0.06), NS	−15 to −25 mg/dL	16–28 RCTs	Low (HbA1c)
Barberry	−2.32% (−3.18,	−24.2 mg/dL	1–2 RCTs*	Very low

Botanical	HbA1c, WMD (95% CI)	FPG, WMD (95% CI)	Contributing trials	GRADE certainty
(Berberis vulgaris)	−1.46)*			
Gymnema sylvestre	↓ (small trials)	↓	Open-label	Insufficient

WMD, weighted mean difference; CI, confidence interval; NS, not statistically significant; ↓, significant reduction reported without a single pooled interval. *Barberry estimate derives from a single small RCT and is highly imprecise. HbA1c 1 mmol/L FPG ≈ 18 mg/dL.

Table 5. Principal mechanisms of action and bioactive constituents

Botanical	Key constituent(s)	Reported glucose-lowering mechanism(s)
Berberine	Berberine (alkaloid)	AMPK activation; KCNH6 (Kv11.2) inhibition → glucose-dependent insulin secretion; suppression of hepatic gluconeogenesis; gut-microbiota modulation; α-glucosidase inhibition.
Fenugreek	4-hydroxyisoleucine, galactomannan, trigonelline	Insulin secretagogue action; soluble-fibre delay of gastric emptying and carbohydrate absorption; improved peripheral insulin sensitivity.
Cinnamon	Cinnamaldehyde, MHCP, procyanidins	Enhanced insulin-receptor autophosphorylation and GLUT4 translocation; α-glucosidase inhibition; antioxidant activity.
Nigella sativa	Thymoquinone	Antioxidant β-cell protection; increased insulin secretion; reduced gluconeogenesis; improved insulin sensitivity.
Silymarin	Silybin / flavonolignans	Potent antioxidant and anti-inflammatory β-cell protection; improved insulin sensitivity.
Ginger / Turmeric	6-gingerol, shogaol; curcumin	NF-κB–mediated anti-inflammatory action; insulin sensitisation; AMPK activation; α-glucosidase inhibition; β-cell protection.
Bitter melon	Charantin, polypeptide-p, vicine	Insulin-mimetic activity; enhanced glucose uptake via AMPK; reduced gluconeogenesis.
Gymnema sylvestre	Gymnemic acids	Reduced intestinal glucose absorption; putative β-cell regeneration; suppression of sweet-taste perception.
Aloe vera	Acemannan, phytosterols	Increased insulin secretion and sensitivity; antioxidant effects.

3.6 Safety, adverse events, and herb–drug interactions

Across the included syntheses, serious adverse events were rare and were not reported at higher rates than placebo for most botanicals [7,8,19]. For berberine, the incidence of total adverse events was actually lower than control (RR 0.73, 95% CI 0.55 to 0.97), with no significant excess of hypoglycaemia [9]. The commonest adverse effects were mild and

gastrointestinal — diarrhoea, abdominal discomfort, nausea — reported most often for bitter melon and fenugreek [7,19]. The two dominant safety concerns are pharmacodynamic and pharmacokinetic: additive hypoglycaemia when insulinotropic or insulin-sensitising herbs are combined with sulfonylureas or insulin, and largely uncharacterised herb–drug interactions, several mediated by cytochrome P450 and P-glycoprotein [23,24]. Table 6 summarises the practical safety profile of each botanical.

Table 6. Safety profile and clinically relevant herb–drug interactions

Botanical	Common / notable adverse effects	Key interactions and cautions
Berberine	Mild GI upset (constipation, diarrhoea)	Potentiates hypoglycaemics; inhibits CYP3A4 and P-glycoprotein (statins, cyclosporine, anticoagulants); avoid in pregnancy and neonates (risk of kernicterus).
Fenugreek	GI symptoms; maple-syrup body odour	Additive with hypoglycaemics and anticoagulants; uterine-stimulant — avoid in pregnancy; possible cross-allergy with legumes/peanut.
Cinnamon (cassia)	Generally well tolerated	Coumarin content risks hepatotoxicity at high or prolonged doses (prefer Ceylon cinnamon); additive glucose lowering.
Nigella sativa	Mild GI symptoms	Additive hypoglycaemia; possible CYP modulation; limited interaction data.
Silymarin	Mild GI/laxative effect; well tolerated	Potential CYP2C9 interaction (e.g. warfarin); monitor when combined with narrow-therapeutic-index drugs.
Ginger / Turmeric	GI symptoms; rare hepatotoxicity (curcumin)	Antiplatelet effect — caution with anticoagulants; curcumin interacts with anticoagulants and chemotherapeutics; regulatory liver-injury warnings for some curcumin products.
Bitter melon	GI symptoms; favism (vicine)	Hypoglycaemic coma and convulsions reported in overdose; abortifacient — avoid in pregnancy.
Gymnema sylvestre	Generally mild	Additive hypoglycaemia; rare hepatotoxicity reports.
Ginseng (adjunctive)	Insomnia, headache	Case reports of hypoglycaemia with oral hypoglycaemics; interacts with warfarin.

3.7 Certainty of evidence

GRADE and AMSTAR-2 appraisal revealed a consistent gradient: effect size and certainty were often inversely related. Ginger and turmeric carried moderate-certainty evidence of a clinically meaningful HbA1c reduction, and berberine's primary outcomes (FPG and HbA1c) were rated moderate certainty in its most rigorous meta-analysis, downgraded principally for risk of bias [9]. By contrast, the herbs with the largest point estimates — silymarin, aloe vera, psyllium — rested on few small trials of low or very low

certainty, and barberry's dramatic estimate derived from a single imprecise RCT [8,20]. Figure 5 displays the distribution of certainty ratings by botanical, and Table 7 provides a GRADE summary of findings for the principal herb–outcome pairs.

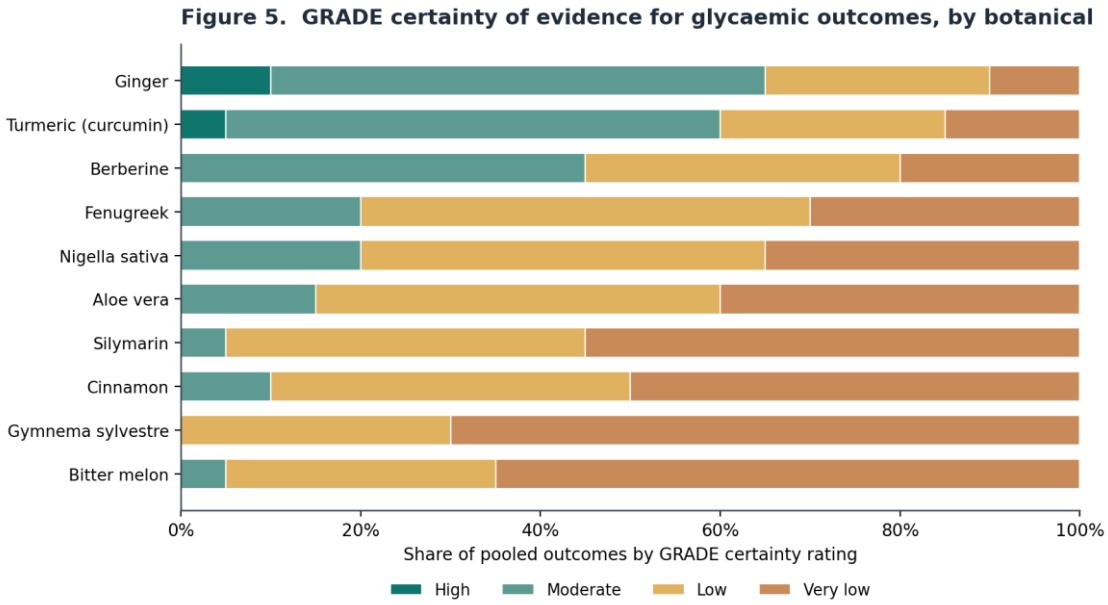

Figure 5. GRADE certainty of evidence for glycaemic outcomes, by botanical, expressed as the approximate share of pooled outcomes at each certainty level. Ginger, turmeric, and berberine combine meaningful effect sizes with comparatively higher certainty.

Table 7. GRADE summary of findings for principal herb–outcome pairs

Botanical	Outcome	Effect (WMD, 95% CI)	Certainty	Main reason(s) for downgrading
Berberine	HbA1c	−0.63% (−0.72, −0.53)	⊕⊕⊕◯ Moderate	Risk of bias (blinding/allocation)
Berberine	FPG	−0.82 mmol/L (−0.95, −0.70)	⊕⊕⊕◯ Moderate	Risk of bias
Ginger	HbA1c	−0.47% (−0.76, −0.17)	⊕⊕⊕◯ Moderate	Inconsistency (heterogeneity)
Turmeric	HbA1c	−0.49% (−0.77, −0.21)	⊕⊕⊕◯ Moderate	Inconsistency
Fenugreek	HbA1c	−0.85% (−1.49, −0.22)	⊕⊕◯◯ Low	Risk of bias, imprecision
Nigella sativa	FPG	−24.2 mg/dL (−39.4, −9.0)	⊕⊕◯◯ Low	Inconsistency, imprecision
Silymarin	HbA1c	−1.07% (−1.73, −0.40)	⊕◯◯◯ Very low	Very serious risk of bias, imprecision
Cinnamon	HbA1c	−0.16% (−0.39, 0.06)	⊕⊕◯◯ Low	Inconsistency; effect not significant

Botanical	Outcome	Effect (WMD, 95% CI)	Certainty	Main reason(s) for downgrading
Bitter melon	HbA1c	−0.26% (−0.49, −0.03)	⊕◯◯◯ Very low	Risk of bias, imprecision

4. DISCUSSION

4.1 Summary of principal findings

This synthesis of 27 quantitative evidence syntheses shows that several herbal medicines achieve glycaemic reductions of clinical interest in T2DM, but that effect size, precision, and certainty vary substantially. The most defensible conclusion is that berberine, ginger, and turmeric combine reductions at or beyond the ≥0.5% HbA1c threshold with moderate-certainty evidence, positioning them as the most promising evidence-based adjuncts. Fenugreek, Nigella sativa, aloe vera, psyllium, and silymarin show comparable or larger point estimates but on weaker evidential foundations, while cinnamon reliably lowers fasting glucose without a dependable HbA1c benefit.

4.2 Comparison with standard pharmacotherapy

Metformin, the first-line agent, typically lowers HbA1c by roughly 1.0–1.5% versus placebo, and most oral hypoglycaemic drugs achieve 0.5–1.0% [8]. Against this benchmark, berberine's −0.63% (moderate certainty) and the −0.47% to −0.49% for ginger and turmeric are clinically relevant, and head-to-head trials suggest berberine's short-term efficacy approaches that of metformin — though small samples, short durations, and predominantly single-region trials preclude any claim of equivalence [9,10]. Berberine's glucose-dependent insulinotropic mechanism is notable because it lowers glucose without increasing hypoglycaemia risk, a theoretical advantage over sulfonylureas. These agents are best conceived not as replacements for guideline therapy but as potential adjuncts, particularly for patients intolerant of metformin, those with cultural preference for botanical therapies, or settings with limited pharmaceutical access.

4.3 Mechanistic plausibility

The mechanistic map (Figure 4, Table 5) reinforces biological plausibility: the botanicals converge on the same pathways targeted by modern drug classes — AMPK activation (berberine, metformin), α-glucosidase inhibition (berberine, cinnamon, ginger; acarbose), insulin secretion (fenugreek, bitter melon; sulfonylureas), and insulin sensitisation (cinnamon, curcumin; thiazolidinediones). The recurrent antioxidant and anti-inflammatory theme is pertinent because oxidative stress and chronic low-grade inflammation are central to β-cell failure in T2DM. This multi-target action is a genuine pharmacological strength but also complicates standardisation and dose–response characterisation.

4.4 Safety and herb–drug interactions

The safety signal across the literature is reassuring for short-term use — no consistent excess of serious adverse events — but incomplete. Fewer than half of trials systematically collected adverse-event data, and herb–drug interaction data are sparse [8,23]. The clinically important risks are additive hypoglycaemia with concurrent antidiabetic drugs and pharmacokinetic interactions via CYP450/P-glycoprotein (notably berberine and curcumin). Product-quality issues — coumarin in cassia cinnamon, contamination or adulteration of some traditional formulations, and rare curcumin-associated hepatotoxicity — further argue for pharmacovigilance and standardised, quality-assured preparations.

4.5 Strengths and limitations

Strengths of this review include its adherence to PRISMA 2020, prioritisation of the highest-level evidence, cross-herb comparison against a pre-specified clinical threshold, and formal GRADE/AMSTAR-2 appraisal. Limitations largely reflect the underlying evidence: high clinical heterogeneity in species, preparation, dose, and duration; frequent methodological weaknesses (inadequate blinding and allocation concealment); geographic concentration of some trials (e.g. berberine trials predominantly from China); short follow-up that may underestimate durable HbA1c effects; and

probable publication bias. Because a pooled cross-herb meta-analysis was not statistically appropriate, effect comparisons are narrative rather than formally ranked.

4.6 Implications for practice and research

For practice, herbal medicines should be positioned as adjuncts to — not substitutes for — guideline-concordant care, with explicit shared decision-making, disclosure of use, and monitoring for hypoglycaemia and interactions, especially when co-prescribed with insulin or sulfonylureas. For research, the field needs adequately powered, long-duration (≥12 months) RCTs using standardised, chemically characterised preparations, reported per the CONSORT extension for herbal interventions, with routine adverse-event capture, herb–drug interaction assessment, and patient-reported outcomes. Table 8 outlines priority research gaps.

Table 8. Priority research gaps and recommendations

Domain	Recommendation
Standardisation	Define and report species, plant part, extract ratio, and quantified marker compound(s) for every trial arm; adopt chemically standardised preparations.
Trial design	Adequately powered, placebo-controlled RCTs with ≥12-month duration and long-term follow-up for micro-/macrovascular outcomes.
Certainty	Prospective registration, allocation concealment, blinding, and PRISMA/CONSORT-herbal reporting to raise evidence certainty above the current low/very-low ceiling.
Safety	Systematic adverse-event capture, dedicated herb–drug interaction (CYP/P-gp) studies, and post-marketing pharmacovigilance registries.
Generalisability	Multi-region trials across diverse ethnic and socio-economic populations, including patients with comorbidity and complications.
Patient outcomes	Incorporate quality-of-life and adherence endpoints alongside HbA1c and FPG.

5. CONCLUSION

Herbal medicines occupy a plausible and popular adjunctive role in the management of type 2 diabetes. The strongest current evidence supports berberine, ginger, and turmeric, which reduce HbA1c by clinically meaningful margins at moderate certainty, with berberine additionally offering a glucose-dependent, low-hypoglycaemia mechanism. Fenugreek, Nigella sativa, aloe vera, psyllium, and silymarin are promising but rest on lower-certainty evidence, and cinnamon's benefit appears limited to fasting glucose. Given persisting heterogeneity, non-standardised preparations, and incomplete safety data, these agents should be used only as monitored adjuncts to guideline-based therapy. Rigorous, standardised, long-term trials are required before any botanical can be recommended as a stand-alone antidiabetic treatment.

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