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SYSTEMATIC REVIEW **OPEN ACCESS**

The Role of Herbal Supplements in Type 2 Diabetes Management: An Evidence from a Systematic Review

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Abstract:

Introduction/ Objective: Despite the increasing global prevalence of diabetes, herbal supplements are becoming increasingly popular as complementary therapies for the management of type 2 diabetes and its complications. This review examines their potential role in glycaemic control and diabetes care.

Methods: A thorough search was conducted across multiple databases, including the Cochrane Library, Scopus, PubMed, and Web of Science, supplemented by manual reviews to identify relevant studies. Key outcomes assessed were glycaemic control, lipid levels, safety, and metabolic markers. Study selection followed the PRISMA flow diagram, and data extraction was performed using a standardized, pilot-tested form. The Cochrane Risk of Bias Tool (RoB 2) was employed to evaluate study quality.

Result: Several herbs, such as cinnamon, fenugreek, ginger, and saffron, showed potential in improving HbA1c, Fasting Blood Glucose (FBG), insulin sensitivity, and cholesterol levels, though some studies reported limited effects on glycaemic control. Curcumin, especially in nano-formulations or paired with piperine, significantly reduced FBG and HbA1c while enhancing β-cell function (HOMA-β). Fenugreek seed powder modestly lowered FBG and HbA1c, with more pronounced benefits on lipids. Ginger supplementation improved FBG, HbA1c, LDL cholesterol, and antioxidant status. Moringa yielded mixed results, with some studies noting postprandial glucose reductions but no significant glycaemic improvements. Saffron improved FBG and lipid profiles without notable effects on inflammation or oxidative stress.

Discussion: Herbal supplements, including cinnamon, curcumin, fenugreek, ginger, Moringa oleifera, and saffron, showed potential benefits in type 2 diabetes management, with several studies reporting improvements in fasting blood glucose, HbA1c, insulin sensitivity, and lipid profiles. Curcumin, cinnamon, fenugreek, and ginger demonstrated more consistent effects, while findings for Moringa oleifera and saffron were variable. Further well-designed trials are needed to confirm their effectiveness.

Conclusion: They may serve as complementary treatments alongside conventional antidiabetic drugs, particularly for patients preferring natural options or those with mild to moderate T2DM. Future research should explore longer-term interventions and combination therapies for more definitive conclusions.

Keywords: Type 2 diabetes, Herbal supplements, Glycaemic control, Insulin sensitivity, Fasting blood glucose, HbA1c.

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1. INTRODUCTION

Diabetes is a long-term health condition brought on by inadequate or inefficient insulin production [1]. Hyperglycaemia from uncontrolled diabetes can damage various body systems, particularly blood vessels and neurons [2]. In 1990, 7% of individuals aged 18 and over had diabetes; by 2022, that number had increased to 14% [3, 4]. The prevalence of untreated diabetes is highest in low- and middle-income nations, with more than half of persons with diabetes aged 30 and older not taking medication for their condition [5]. In 2021, diabetes was the cause of 1.6 million fatalities, with 47% of all deaths taking place in those under 70 [6]. It was also responsible for 11% of cardiovascular fatalities and 530,000 deaths from renal illness [7]. A balanced diet, regular exercise, maintenance of a healthy weight, and quitting tobacco use can all help prevent or postpone the onset of type 2 diabetes (T2DM) [8].

Poor glycaemic control and the subsequent micro- and macrovascular consequences of T2DM are the result of noncompliance with standard treatment regimens [9, 10]. Patients from ethnic minorities are more likely to have poor diabetes management, increasing their risk of morbidity, death, and disability from T2DM complications [11]. This might be partially explained by decreased health knowledge and lower adherence to conventional medications [12]. Despite having high blood glucose, some individuals may put off seeing a doctor or avoid using conventional medications because they are concerned about negative effects [13]. For instance, between 30 and 50 percent of patients are deterred from starting insulin because of fear, anxiety, or discomfort with injections [14].

Individuals of some ethnic minorities are more inclined to choose herbal remedies over conventional medical care [15]. In addition to standard medications, 50–60% of individuals with T2DM worldwide utilise some form of alternative therapy [16, 17]. Approximately two-thirds of South Asian participants in a UK study reported using herbal medications for a variety of conditions, including diabetes [18]. According to a previous systematic review, glycaemic management may be improved by the use of some herbal therapies in conjunction with conventional medical care [19]. However, most prior reviews have focused on single herbs or isolated biochemical mechanisms, with limited integration of patient-centered and practice-oriented perspectives. The novelty of the present study lies in its comprehensive qualitative synthesis of the most commonly used herbal remedies for type 2 diabetes mellitus (T2DM), with particular emphasis on comparative effectiveness, dosage patterns, and contextual application across diverse populations. The ultimate objective is to generate evidence-based, clinically relevant insights that can support both patients and healthcare professionals in making informed decisions regarding the use of herbal therapies for glycaemic management.

2. MATERIAL AND METHODS

2.1. Protocol and Registration

2.1.1. Protocol Development

A thorough protocol was prepared before the initiation of the review, detailing the study question, inclusion and exclusion criteria, search strategy, data extraction techniques, and intended analysis.

2.2. Research Question

The review aims to address the following research question: “What is the efficacy and safety of herbal interventions (cinnamon, curcumin, fenugreek, ginger, moringa, saffron) in improving glycaemic control, lipid profiles, and other metabolic parameters in patients with T2DM?”

2.3. Eligibility Criteria

The PICO questions were assessed in this systematic review:

Population: Adult patients (≥18 years) diagnosed with T2DM.

Intervention: Any herbal intervention (*e.g.*, cinnamon, curcumin, fenugreek, ginger, moringa, saffron) delivered in any form (*e.g.*, capsules, powders, extracts).

Control: Placebo, routine care, or other active therapies.

Outcomes: Primary outcomes were glycaemic control (*e.g.*, fasting blood glucose, glycated haemoglobin (HbA1c), insulin resistance) and lipid profiles (*e.g.*, total cholesterol, LDL, HDL, triglycerides). Secondary outcomes included safety profiles (*e.g.*, adverse events) and various metabolic markers (*e.g.*, body weight, oxidative stress).

Eligible studies were randomized controlled trials (RCTs), including double-blind, triple-blind, and placebo-controlled designs, published in English. Studies involving participants with type 1 diabetes, gestational diabetes, or non-diabetic populations were excluded. Non-randomized studies, observational designs, case reports, review articles, animal studies, and studies with insufficient methodological clarity or incomplete data were also excluded. Additionally, trials employing combination therapies in which the independent effect of the herbal intervention could not be isolated were excluded.

2.4. Search Strategy Databases

The strategy of this research was undertaken in multiple search engines and databases (the Cochrane Library, Scopus, PubMed, and Web of Science). The search method included a combination of MeSH terms and phrases linked to T2DM, herbal therapies, and outcomes of interest. Examples of search keywords include: “type 2 diabetes mellitus”, “herbal medicine”, “cinnamon”, “curcumin”, “fenugreek”, “ginger”, “moringa”, “saffron”, “glycaemic control”, and “lipid profile”.

2.5. Study Selection Screening

Two independent reviewers examined the titles and

abstracts of all identified papers to determine eligibility based on the inclusion and exclusion criteria.

Full-Text Review: The complete texts of potentially eligible papers were retrieved and read separately by two reviewers. Disagreements were addressed by discussion or contact with a third reviewer.

The PRISMA flow diagram was used to describe the study selection process, with the number of studies identified and excluded for any reasons at each stage.

2.6. Data Extraction

Data Extraction Form: A standardised data extraction form was designed and pilot tested. Data were extracted separately by two reviewers, and differences were handled by consensus.

2.6.1. Extracted Data

Study characteristics: Author, year, country, study methodology, sample size.

Participant characteristics: Age, gender, and baseline glucose levels.

Intervention details: Type of herb, dose, duration, method of administration.

Comparator: Placebo or active control.

Outcomes: Glycaemic control (fasting glucose, HbA1c), lipid profiles (*e.g.*, LDL, HDL), safety (adverse events), and other metabolic parameters.

In addition, the completed PRISMA checklist is provided as a supplementary file (Supplementary File **1**).

2.7. Risk of Bias Assessment Tool

The risk of bias was assessed using the Cochrane Risk of Bias Tool (RoB-2) for RCTs. The assessed domains were bias originating from the randomisation method, bias owing to variations from desired interventions, bias owing to missing outcome data, bias in measuring the outcome, and bias in the selection of the reported outcome. Judgment: Each domain was rated as “low risk,” “some concerns,” or “high risk” of bias. The total RoB for each study and in summary was presented.

2.8. Quality Appraisal and Assessment

The Critical Appraisal Skills Programme (CASP) tool was used to assess the quality of the 34 included studies. An 11-item checklist was used to assess the quality of these included studies.

3. RESULTS

We obtained a total of 2223 studies, of which 1863 remained after removing duplicates. After reviewing the titles and abstracts, 964 items were removed, leaving 899 publications. During the full-text review, 865 papers were excluded. Finally, 34 studies fulfilled the inclusion criteria (Fig. **1**).

Focusing on the use of several herbs for controlling T2DM, Table **1** presents a summary of the included studies’ characteristics [20-52]. It involves 28 studies conducted across several countries, including China, Brazil, Iran, Portugal, Thailand, Ethiopia, India, Saudi Arabia, Pakistan, Cameroon, and Algeria.

Table 1. Characteristics of the included studies.

First Author, Year/Refs.	Country	Study Design	Overall Sample Size
Anderson, *et al.* 2016 [20]	China	Placebo-controlled double-blind trial	137
Lira Neto, *et al.* 2021 [21]	Brazil	Randomized triple-blind placebo-controlled trial	140
Mirfeizi, *et al.* 2016 [22]	Iran	Triple-blind randomized clinical trial	102
Rachid, *et al.* 2022 [23]	Portugal	Randomized controlled trial	36
Talaei, *et al.* 2017 [24]	Iran	Double-blind randomized placebo-controlled trial	39
Zare *et al.*, 2018 [25]	Iran	Triple-blind placebo-controlled randomized clinical trial	140
Adab *et al.* 2019 [26]	Iran	Double-blind RCT	80
Asadi *et al.* 2019 [27]	Iran	Double-blind randomized, parallel, placebo-controlled clinical trial	80
Hodaei *et al.* 2019 [28]	Iran	Randomized, double-blind, placebo-controlled trial	44
Yaikwawong *et al.* 2024 [29]	Thailand	Randomized, double-blind, placebo-controlled trial	229
Neta *et al.* 2021 [30]	Brazil	Randomized double-blind placebo-controlled clinical trial	61
Panahi Yunes *et al.* 2018 [31]	Iran	Randomized double-blind placebo-controlled trial	100
Rahimi H.R. *et al.* 2016 [32]	Iran	Double-blind randomized placebo-controlled trial	70
Genet Alem Geberemeskel, *et al.* 2019 [33]	Ethiopia	Experimental study using quantitative methods	114
Amit D. Kandhare, *et al.* 2018 [34]	India	12-week, randomized, double-blind, placebo-controlled, multi-center	119
Rania A Najdi, *et al.* 2019 [35]	Saudi Arabia	Open-label randomized controlled trial	12
Narsingh Verma, *et al.* 2016 [36]	India	Multicenter, placebo-controlled, double-blind, add-on clinical study	154
Suchitra, *et al.* 2015 [37]	India	Randomized controlled trial	60
Arzati *et al.*, 2017 [38]	Iran	Double-blind placebo-controlled trial	50
Carvalho *et al.*, 2020 [39]	Brazil	Randomized double-blind clinical trial	103
Ghoreishi *et al.*, 2024 [40]	Iran	Double-blind placebo-controlled trial	76
Khandouzi *et al.*, 2015 [41]	Iran	Double-blind placebo-controlled trial	41
Shidfar *et al.*, 2015 [42]	Iran	Double-blind placebo-controlled trial	45

(Table 1) contd.....

First Author, Year/Refs.	Country	Study Design	Overall Sample Size
Ahmad *et al.* 2018 [43]	Pakistan	Randomized crossover	20
Taweerutchana *et al.* 2017 [44]	Thailand	Randomized placebo-controlled	32
Sissoko *et al.* 2020 [45]	Cameroon	Pilot clinical trial	70
Hameed *et al.* 2023 [46]	Pakistan	Prospective placebo-controlled	24
Leone *et al.* 2018 [47]	Algeria	Randomized controlled trial	27
Moravej Aleali, *et al.* 2019 [48]	Iran	Double-blind randomized clinical trial	64
Azimi, *et al.* 2015 [49]	Iran	Randomized controlled, single-blind, placebo-controlled clinical trial	204
Ebrahimi, *et al.* 2019 [50]	Iran	Triple-blinded randomized clinical trial	54
Milajerdi, *et al.* 2018 [51]	Iran	Triple-blinded randomized clinical trial	54
Shahbazian, *et al.* 2019 [52]	Iran	Double-blind randomized clinical trial	64

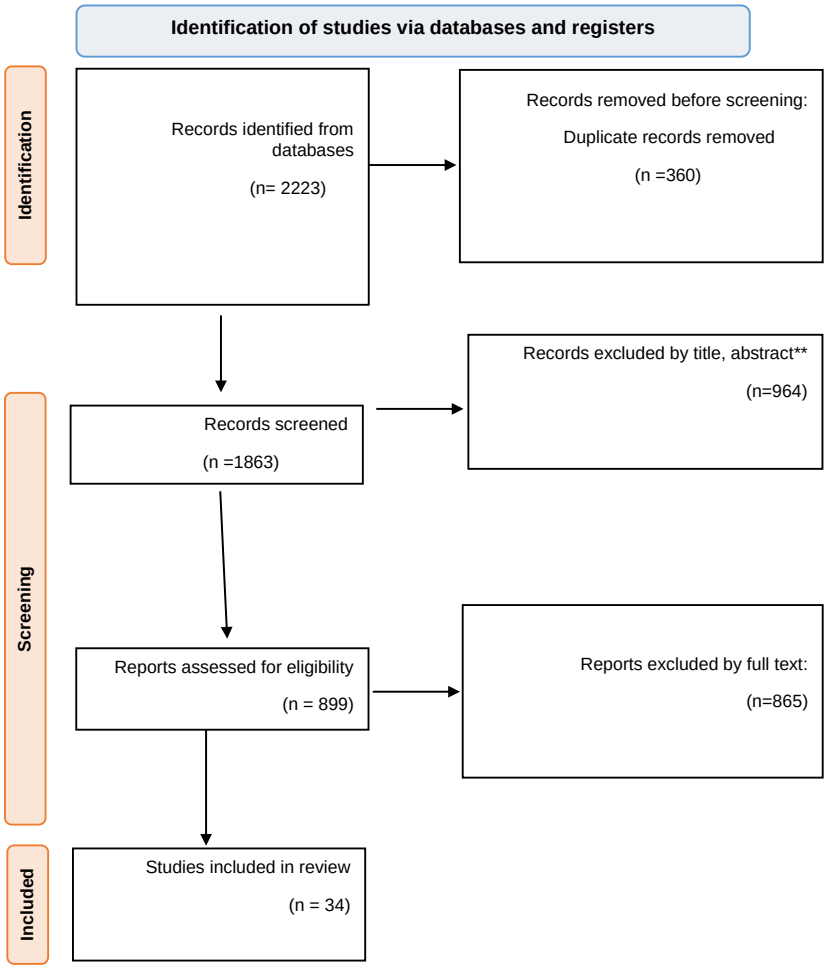

Fig. (1). PRISMA flow diagram.

Out of 28 studies, 14 were carried out in Iran, highlighting the country's important commitment to diabetes research and herbal remedies. Other countries with several included studies were Thailand (2 studies), India (3 studies), and Brazil (3 studies). Despite a focus on areas where traditional medicine is more common, this geographical variety points to a worldwide interest in herbal treatment for diabetes.

Considered the gold standard for clinical research, RCTs were the most common form of investigation. Most of these RCTs were double- or triple-blind, guaranteeing a significant degree of rigor in reducing bias. Some studies, such as Najdi *et al.* (2019), were open-label RCTs; although less precise than blinded studies, these methods can still offer insightful analysis [35]. Pilot clinical trials (Sissoko *et al.*, 2020) and experimental investigations

(Geberemeskel *et al.*, 2019) evidence the use of a spectrum of methodological techniques, from exploratory to confirmatory research [33, 45].

Sample sizes varied widely throughout the research, ranging from as few as 12 (Najdi *et al.*, 2019) to as high as 229 participants (Yaikwawong *et al.*, 2024) [29, 35]. The majority of studies had sample sizes between 30 and 140 individuals, which is normal for clinical trials in this sector. However, smaller sample sizes (*e.g.*, Hameed *et al.*, 2023, with 24 participants) may restrict the generalisability of the findings; larger investigations (Yaikwawong *et al.*, 2024) give more substantial evidence [29, 46].

Table **2** presents detailed information on the interventions and control groups of the included trials, concentrating on the exact herbal therapies, doses, durations, and control conditions employed in each experiment.

3.1. Herbal Interventions

The table highlights a range of studied herbal therapies, including cinnamon, curcumin, fenugreek, ginger, moringa, and saffron. Each plant was investigated in several trials, with variations in dosage and duration.

Cinnamon was the most frequently investigated herb, included in studies such as Anderson *et al.*, 2016 (500 mg/day), Lira Neto *et al.*, 2022 (3 g/day), and Zare *et al.*, 2018 (500 mg capsules, twice a day) [20, 21, 25]. The dosages vary from 500 mg to 6 g per day, suggesting a wide range of studied quantities.

Curcumin (the active component of turmeric) was also frequently investigated, with doses ranging from 80 mg/day (*e.g.*, Asadi *et al.*, 2019) to 1500 mg/day (*e.g.*, Hodaei *et al.*, 2019, and Yaikwawong *et al.*, 2024). Some research, such as Panahi *et al.* (2018), coupled curcumin with piperine (5 mg/day) to increase bioavailability [27-29, 31].

Table 2. Characteristics of intervention and control.

First Author, Year/Refs.	Intervention Group (Intervention & Sample Size)	Dosage	Duration	Control Group (Control & Sample Size)
Anderson, *et al.* 2016 [20]	Cinnamon extract (64)	500 mg/day	2 months	Placebo (73)
Lira Neto, *et al.* 2021 [21]	Cinnamon (71)	3 g/day	3 months	Placebo (69)
Mirfeizi, *et al.* 2016 [22]	Cinnamon (27), Whortleberry (30)	1 g/day	3 months	Placebo (45)
Rachid, *et al.* 2022 [23]	Cinnamon extract (18)	6 g/100 mL	Single dose	Control (18)
Talaei, *et al.* 2017 [24]	Cinnamon (20)	3 g/day	8 weeks	Placebo (19)
Zare *et al.*, 2018 [25]	Cinnamon (70)	500 mg capsules twice daily	3 months	Placebo (70)
Adab *et al.* 2019 [26]	Turmeric (40)	2,100 mg/day	8 weeks	Placebo (40)
Asadi *et al.* 2019 [27]	Nano-curcumin (40)	80 mg/day	8 weeks	Placebo (40)
Hodaei *et al.* 2019 [28]	Curcumin (21)	1500 mg/day	10 weeks	Placebo (23)
Yaikwawong *et al.* 2024 [29]	Curcumin (114)	1500 mg/day	12 months	Placebo (115)
Neta *et al.* 2021 [30]	*Curcuma longa* L. (33)	500 mg/day with piperine 5 mg	120 days	Placebo (28)
Panahi Yunes *et al.* 2018 [31]	Curcuminoids (500 mg/day) + Piperine (5 mg/day) (n=50)	500 mg/day curcuminoids + 5 mg/day piperine	3 months	Placebo (n=50)
Rahimi H.R. *et al.* 2016 [32]	Nano-curcumin (n=35)	80 mg/day	3 months	Placebo (n=35)
Genet Alem Geberemeskel, *et al.* 2019 [33]	Fenugreek seed powder solution (57)	25 g twice daily	1 month	Metformin (57)
Amit D. Kandhare, *et al.* 2018 [34]	IDM1 (60)	700 mg three times daily	12 weeks	Placebo (59)
Rania A Najdi, *et al.* 2019 [35]	Fenugreek (6)	2 g/day	12 weeks	Glibenclamide (6)
Narsingh Verma, *et al.* 2016 [36]	Fenfuro (77)	500 mg bid	90 days	Placebo (77)
Suchitra, *et al.* 2015 [37]	Fenugreek (30)	Not clearly mentioned	Not mentioned	Control (Group C)
Arzati *et al.*, 2017 [38]	Ginger (25)	2000 mg/day	10 weeks	Placebo (25)
Carvalho *et al.*, 2020 [39]	Ginger (47)	1200 mg/day	90 days	Placebo (56)
Ghoreishi *et al.*, 2024 [40]	Ginger (36)	2000 mg/day	3 months	Placebo (36)
Khandouzi *et al.*, 2015 [41]	Ginger (22)	2000 mg/day	12 weeks	Placebo (19)
Shidfar *et al.*, 2015 [42]	Ginger (22)	3000 mg/day	12 weeks	Placebo (23)
Ahmad *et al.* 2017 [43]	Moringa (5% w/w) & SC (3% w/w)	Cookies	1 meal	CC (20)
Taweerutchana *et al.* 2017 [44]	Moringa leaf capsules (16)	8 g/day	4 weeks	Placebo (16)
Sissoko *et al.* 2020 [45]	Moringa leaf powder (35)	1g & 2g	1 day	Control (35)
Hameed *et al.* 2023 [46]	Moringa leaf capsules (12)	3g & 6g	3 months	Placebo (12)
Leone *et al.* 2018 [47]	Moringa leaf powder (20 g)	20 g	1 meal	Control meal (27)
Moravej Aleali, *et al.* 2019 [48]	Saffron (32)	15 mg/day	3 months	Placebo (32)
Azimi, *et al.* 2015 [49]	Saffron (42)	1 g/day	8 weeks	Control (39)
Ebrahimi, *et al.* 2019 [50]	Saffron (27)	15 mg/capsule twice daily	8 weeks	Placebo (27)
Milajerdi, *et al.* 2018 [51]	Saffron (26)	15 mg/capsule twice daily	8 weeks	Placebo (26)
Shahbazian, *et al.* 2019 [52]	Saffron (32)	15 mg/capsule twice daily	3 months	Placebo (32)

Fenugreek was explored in studies like Geberemeskel *et al.* (2019) (25 g twice a day) and Najdi *et al.* (2019) (2 g/day), with varied doses and durations [33, 35]. Ginger was examined in dosages ranging from 1200 mg/day (*e.g.*, Carvalho *et al.*, 2020) to 3000 mg/day (*e.g.*, Shidfar *et al.*, 2015), with most research utilising around 2000 mg/day [39, 42]. Moringa was investigated in several forms, including capsules (*e.g.*, Taweerutchana *et al.*, 2017) and leaf powder (*e.g.*, Sissoko *et al.*, 2020), with doses ranging from 1 g to 8 g/day [44, 45]. Saffron was evaluated in dosages of 15 mg/day (*e.g.*, Moravej Aleali *et al.*, 2019) to 1 g/day (*e.g.*, Azimi *et al.*, 2015), with most research utilising lower quantities [48, 49].

3.2. Dosages and Durations

The doses of herbal therapies used varied widely between different studies, reflecting the variation in traditional and experimental applications of these plants. For example, cinnamon dosages ranged from 500 mg/day to 6 g/day, with doses between 500 mg and 3 g/day the most common. Curcumin doses ranged from 80 mg/day to 1500 mg/day, with some studies mixing it with piperine to increase absorption. Fenugreek dosages ranged from 2 g/day to 25 g twice daily.

There was also a large variation between the duration of treatments, from single doses (*e.g.*, Rachid *et al.*, 2022) to 12 months (*e.g.*, Yaikwawong *et al.*, 2024) [23, 29]. Most interventions lasted between 8 weeks and 3 months, suitable for testing short- to medium-term effects on glycaemic management and other metabolic parameters.

3.3. Control Groups

The majority of research used placebo-controlled designs, which are critical for assessing the efficacy of the herbal therapies. For instance, placebo groups were included in the designs of Anderson *et al.* (2016) and Lira Neto *et al.* (2022) to assess the effects of cinnamon extract and Adab *et al.* (2019) and Asadi *et al.* (2019) to examine the effects of curcumin and nano-curcumin, respectively [20,21.26.27]. Some research, such as Geberemeskel *et al.* (2019), instead used active controls (*e.g.*, metformin) to test the efficacy of herbal remedies against conventional diabetic drugs [33]. A small number of studies, such as Rachid *et al.* (2022), employed non-placebo controls (control groups without any intervention), which may restrict the capacity to make significant conclusions about the efficacy of the herbal intervention [23].

3.4. Sample Sizes in Intervention and Control Groups

The overall sample sizes (Table **1**) and those for control groups (Table **2**) are presented to allow for an assessment of the balance between groups. For instance, Anderson *et al.* (2016) reported on 64 participants in the cinnamon group and 73 in the placebo group [20]. Lira Neto *et al.* (2022) had 71 participants in the cinnamon group, and in the placebo group, 69 participants [21]. Most investigations have somewhat balanced group sizes, which is critical for assuring the validity of the statistical comparisons. The characteristics of the study participants, such as their age, gender distribution, baseline blood glucose levels, and final blood glucose levels following intervention, are reported in Table **3**.

3.5. Age of Participants

Different studies included a range of ages, from younger (Ahmad *et al.* 2017; mean age: 24.1 years) to older individuals (Anderson *et al.* 2016; mean age: 61.3 years) [20, 43]. The majority of studies used middle-aged to older participants, in line with the demographic typically affected by T2DM.

3.6. Sex Distribution

Sex distribution also varied between studies; some used a more balanced sample (*e.g.*, Anderson *et al.* (2016), with 65.7% male participants) while others studied a predominantly female population (*e.g.*, Yaikwawong *et al.* (2024), with 85% female participants) [20, 29]. In Rahimi *et al.* (2016), the intervention group (nano-curcumin) had a balanced gender distribution of 51.5% females, 48.5% males [32].

3.7. Initial Blood Sugar Levels

Most studies provide baseline glucose readings from participants (Table **3**), indicating the severity of diabetes in the research populations. The large range of baseline glucose levels is a reflection of disparities in the severity of diabetes between patient populations and differences in inclusion criteria between studies. Baseline glucose levels ranged from 8.85 mmol/L (Anderson *et al.*, 2016) to 123.65 mg/dL (Yaikwawong *et al.*, 2024) and 180 mg/dL (Mirfeizi *et al.*, 2016) [20, 22, 29]. It is difficult to assess the severity of diabetes across all included studies, as some, such as Geberemeskel *et al.* (2019), describe aberrant baseline glucose levels without using precise values [33].

3.8. Final Blood Sugar Levels

Most studies also provide the end glucose levels following the intervention (Table **3**), allowing evaluation of the effects of herbal treatments on lowering blood glucose levels.

For example, Anderson *et al.* (2016) reported a small decrease in final glucose levels of 8.19 mmol/L [20]. Yaikwawong *et al.* (2024) recorded an average final glucose level of 115.49 mg/dL, significantly lower than the baseline [29]. Rahimi *et al.* (2016) reported a final mean glucose level of 118.38 mg/dL, which was lower than that of the placebo group [32]. Certain studies, such as Zare *et al.* (2018), suggest a drop in glucose levels based on the data but do not provide the final values [25].

3.9. Additional Baseline Features

Additional baseline variables, such as body mass index (BMI), lipid profiles, and insulin levels, are provided by certain studies and are crucial for comprehending the overall metabolic health of study participants. For instance, baseline insulin, cholesterol, and glucose values are reported by Panahi *et al.* (2018), while Rahimi *et al.* (2016) offer glucose levels with comprehensive baseline lipid profiles (TC, TG, LDL-C, and HDL-C) [31, 32].

Table 3. Characteristics of the study participants.

First Author, Year/Refs.	Participants Age	Participants Gender	Baseline Glucose	Final Glucose
Anderson, *et al.* 2016 [20]	61.3 ± 0.8 years	65.7% Male	8.85 ± 0.36 mmol/L	8.19 ± 0.29 mmol/L
Lira Neto, *et al.* 2021 [21]	62 years	71.8% Female	8.85 ± 0.36 mmol/L	8.19 ± 0.29 mmol/L
Mirfeizi, *et al.* 2016 [22]	52-55 years	11.1-30% Male	180 ± 56 mg/dL	155 ± 40 mg/dL
Rachid, *et al.* 2022 [23]	63.5 ± 1.6 years	16.7% Male	8.10 ± 0.75 mmol/L	9.77 ± 4.58 mmol/L
Talaei, *et al.* 2017 [24]	57.6 ± 8.7 years	38.5% Male	183.85 ± 36.16 mg/dL	172.20 ± 44.86 mg/dL
Zare *et al.*, 2018 [25]	30-80 years	Male and Female	FPG: 162.6±30.0 mg/dl	Not explicitly stated in the abstract, but implied to decrease
Adab *et al.* 2019 [26]	30-70 years	51% Female, 49% Male	133.79 ± 25.60	131.64 ± 28.33
Asadi *et al.* 2019 [27]	30-60 years	Majority Female (87.5% female)	165.7 ± 52.3	150.9 ± 58.1
Hodaei *et al.* 2019 [28]	40-70 years	Majority Female (66.7% female)	160 ± 35	153 ± 33
Yaikwawong *et al.* 2024 [29]	≥35 years	Majority Female (85% female)	123.65 ± 1.73	115.49 ± 1.70
Neta *et al.* 2021 [30]	62.5 ± 11.0 years	Majority Female (77% female)	203.9	197.3
Panahi Yunes *et al.* 2018 [31]	18–65 years	25 males, 25 females in both groups	163 ± 37 mg/dL (curcuminoids), 174 ± 33 mg/dL (placebo)	154 ± 34 mg/dL (curcuminoids), 171 ± 26 mg/dL (placebo)
Rahimi H.R. *et al.* 2016 [32]	56.34 ± 11.17 years (Nano-curcumin), 60.95 ± 10.77 years (Placebo)	Male: 17(48.5%), Female: 18(51.5%) (Nano-curcumin); Male: 14(40%), Female: 21(60%) (Placebo)	135.5 ± 51.33 mg/dL (Nano-curcumin), 171.2 ± 50.0 mg/dL (Placebo)	118.38 ± 11.95 mg/dL (Nano-curcumin), 146.32 ± 46.06 mg/dL (Placebo)
Genet Alem Geberemeskel, *et al.* 2019 [33]	Newly diagnosed	Both sexes	Abnormal	Reduced significantly
Amit D. Kandhare, *et al.* 2018 [34]	Mean age: 51.48 years	Both sexes	Abnormal	Reduced significantly
Rania A Najdi, *et al.* 2019 [35]	>18 years	Both sexes	≥140 mg/dL	Reduced insignificantly
Narsingh Verma, *et al.* 2016 [36]	25-60 years	Both sexes	≤180 mg/dL	Reduced significantly
Suchitra, *et al.* 2015 [37]	Not mentioned	Not mentioned	Not mentioned	Not mentioned
Arzati *et al.*, 2017 [38]	30 to 60 years old	Mixed	189.4 ± 88.24	162.84 ± 64.10
Carvalho *et al.*, 2020 [39]	20 to 80 years old	Mixed	203.60 ± 88.24	174.05 ± 64.10
Ghoreishi *et al.*, 2024 [40]	20 to 65 years old	Mixed	174.5 ± 70.7	166.5 ± 68.1
Khandouzi *et al.*, 2015 [41]	20 to 60 years old	Mixed	161.50 ± 58.01	142.09 ± 47.90
Shidfar *et al.*, 2015 [42]	20 to 60 years old	Mixed	161.5 ± 58	142.09 ± 47.9
Ahmad *et al.* 2017 [43]	24.1 ± 1.33	10 males, 10 females	Not specified	Not specified
Taweerutchana *et al.* 2017 [44]	55 ± 11	Mixed	138 ± 36 mg/dl	Not specified
Sissoko *et al.* 2020 [45]	Diabetic: 45.8 ± 10.6 Nondiabetic: 50.1 ± 11.6	Mixed	Diabetic: 140 ± 9 mg/dl Nondiabetic: 86.2 ± 8.4 mg/dl	Diabetic: 135 ± 11 mg/dl Nondiabetic: 84 mg/dl
Hameed *et al.* 2023 [46]	57 ± 9.2	Mixed	140 ± 9 mg/dl	129.28 mg/dl
Leone *et al.* 2018 [47]	For healthy: 42 ± 11 Diabetic: 62 ± 9	Mixed	Healthy: 86.2 ± 8.4 mg/dl Diabetic: 315 ± 15 mg/dl	For healthy: 106 ± 3 mg/dl Diabetic: 296 ± 17 mg/dl
Moravej Aleali, *et al.* 2019 [48]	Mean: 52.4±13	Female: 24 (75%), Male: 8 (25%)	173.2±73.9	147.9±53.5
Azimi, *et al.* 2015 [49]	Mean: 54.33±0.5	Not specified	Not specified	Not specified
Ebrahimi, *et al.* 2019 [50]	Mean: 54.59±7.09	Not specified	128.84±31.86	146.54±41.86
Milajerdi, *et al.* 2018 [51]	Mean: 53.5±9.9	Not specified	164.36±40.88	166.96±41.86
Shahbazian, *et al.* 2019 [52]	Mean: 53.5±9.9	Female: 24 (75%), Male: 8 (25%)	173.2±73.9	147.9±53.5

The main results and conclusions of the included studies are summarised in Supplementary 1, which focuses on how different herbal therapies affect lipid profiles, glycaemic management, and other metabolic parameters in individuals with T2DM.

3.10. Glycaemic Management

According to several included studies, postprandial glucose (PPG), HbA1c, and fasting blood glucose (FBG) levels significantly improved after herbal therapies. Anderson *et al.* (2016) reported that cinnamon extract

enhanced insulin sensitivity (HOMA-IR) and decreased FBG by 0.66 mmol/L [20]. Yaikwawong *et al.* (2024) observed that curcumin supplements dramatically decreased HbA1c (6.12% *vs.* 6.47% in the placebo group) and FBG (115.49 mg/dL *vs.* 130.71 mg/dL in the placebo group) [29]. Meanwhile, Rahimi *et al.* (2016) showed that nano-curcumin decreased HbA1c by 0.9% and FBG by 17.12 mg/dL when compared to placebo [32]. However, other investigations, such as Talaei *et al.* (2017), found no effect of cinnamon supplements on glycaemic control (FBG, HbA1c, HOMA-IR) [24].

3.11. Lipid Profiles

Numerous studies document changes in lipid profiles, including increases in HDL-C and decreases in TG, TC, and LDL-C. According to Geberemeskel *et al.* (2019), fenugreek seed powder increased HDL-C (by 21.7%) while considerably lowering TC (by 13.6%), TG (by 23.53%), and LDL-C (by 23.4%) [33]. According to Neta *et al.* (2021), taking supplements of *Curcuma longa L.* increased HDL-C and decreased TG levels by 21% [30]. According to Shidfar *et al.* (2015), ginger supplements dramatically raised HDL-C levels and decreased LDL-C levels [42]. Nevertheless, certain studies, such as Kandhare *et al.* (2018), indicated that herbal therapies did not significantly alter lipid profiles [34].

3.12. The Function of Pancreatic β-cells and Insulin Sensitivity

Improvements in pancreatic β-cell function (HOMA-β) and HOMA-IR were reported in certain investigations. Yaikwawong *et al.* (2024) observed decreased HOMA-IR and enhanced HOMA-β after their curcumin intervention; however, this was contradicted by another study, which found no effect (Hodaei *et al.*, 2019) [28, 29]. According to Panahi *et al.* (2018), curcuminoids and piperine decreased FBG levels and enhanced insulin sensitivity [31].

3.13. Oxidative Stress and Inflammation

Several studies showed decreases in oxidative stress and inflammatory markers after herbal therapy. According to Shidfar *et al.* (2015), ginger supplements raised antioxidant capacity (TAC) and decreased oxidative stress indicators (such as Malondialdehyde (MDA)) [42]. Moravej Aleali *et al.* (2019) reported that saffron enhanced antioxidant status and decreased inflammatory indicators (hs-CRP) [48]. However, Shahbazian *et al.* (2019) found no effect of saffron supplementation on inflammatory biomarkers like TNF-α or IL-6 [52].

3.14. Body Mass and Anthropometric Measurements

Following herbal therapies, some studies showed changes in waist circumference, body weight, and BMI. Adab *et al* (2019) found that turmeric supplements significantly lowered body weight and BMI [26]. Hodaei *et al.* (2019) observed decreased hip circumference and weight after curcumin treatment compared to placebo [28]. Nevertheless, other studies, including Talaei *et al.* (2017), indicated no discernible effects on body weight or BMI after cinnamon supplementation [24].

The conclusions varied widely between studies. Numerous authors concluded that lipid profiles, glycaemic management, and other metabolic parameters were improved by the specific herbal therapy given. Anderson *et al.* (2016) stated that in individuals with high blood glucose, cinnamon extract decreased FBG, insulin, and cholesterol levels [20]. Yaikwawong *et al.* (2024) reported that curcumin decreased FBG, decreased insulin resistance, and enhanced β-cell activity [29]. However, in other reports, such as Rachid *et al.* (2022), the herbal intervention had no discernible impact on glycaemic control (*e.g.*, postprandial glucose response) or other measures [23].

3.15. Quality Assessment of the Included Studies

The risk of bias assessment identified five forms of bias: randomisation, variations from intended intervention, missing outcome data, assessment of outcome, and selection of reported results. Most studies exhibited minor risks of bias (Figs. **2** and **3**). Green circles indicate a low risk in all domains. Some studies (Ahmad *et al.*, 2017; Sissoko *et al.*, 2020; Azimi *et al.*, 2015; Rahimi *et al.*, 2016; Verma *et al.*, 2016; and Suchitra *et al.*, 2015) exhibit moderate concerns, with yellow circles in one or more areas [32, 36, 37, 43-45, 49]. Domains D1 (randomisation procedure) and D4 (measuring of outcome) typically caused concern. A high risk of bias was detected for certain studies, with red markers suggesting a high risk in at least one category. These studies may have problems with randomisation or group allocation techniques (Taweerutchana *et al.*, 2017; Hameed *et al.*, 2023; Leone *et al.*, 2018) [44, 46, 47]. Overall, most studies were deemed low risk, fulfilling essential methodological quality requirements. A few studies exhibited some concerns, and a few presented substantial risks in certain domains.

3.16. Quality Appraisal and Assessment

Upon the eleven items included for the quality of this study, the quality assessment showed that all studies addressed a clearly formulated research question, and their participants were randomised to the interventions. Suchitra (2015) did not report some of participant basic characteristics and baseline glucose levels. Besides, Azimi (2015), Ebrahimi (2019), and Milajerdi (2018) did not mention the gender distribution in the study, neglecting the gender effect on the study outcomes. Regarding the study duration, Yaikwawong's 2024 study continued the study for 12 months, including the probability of long-lasting effect of curcumin. While Rahimi H.R. 2016 took only 3 months of therapy, this may not give the long-lasting effect of the same drug. Because these studies tested a safe herbal product, the benefits of the experimental intervention outweigh the harms, neglecting the costs' effect. All studies with blind controlled trials affirmed the blindness, except for Rania A Najdi, 2019 [35], who reported an open-label study.

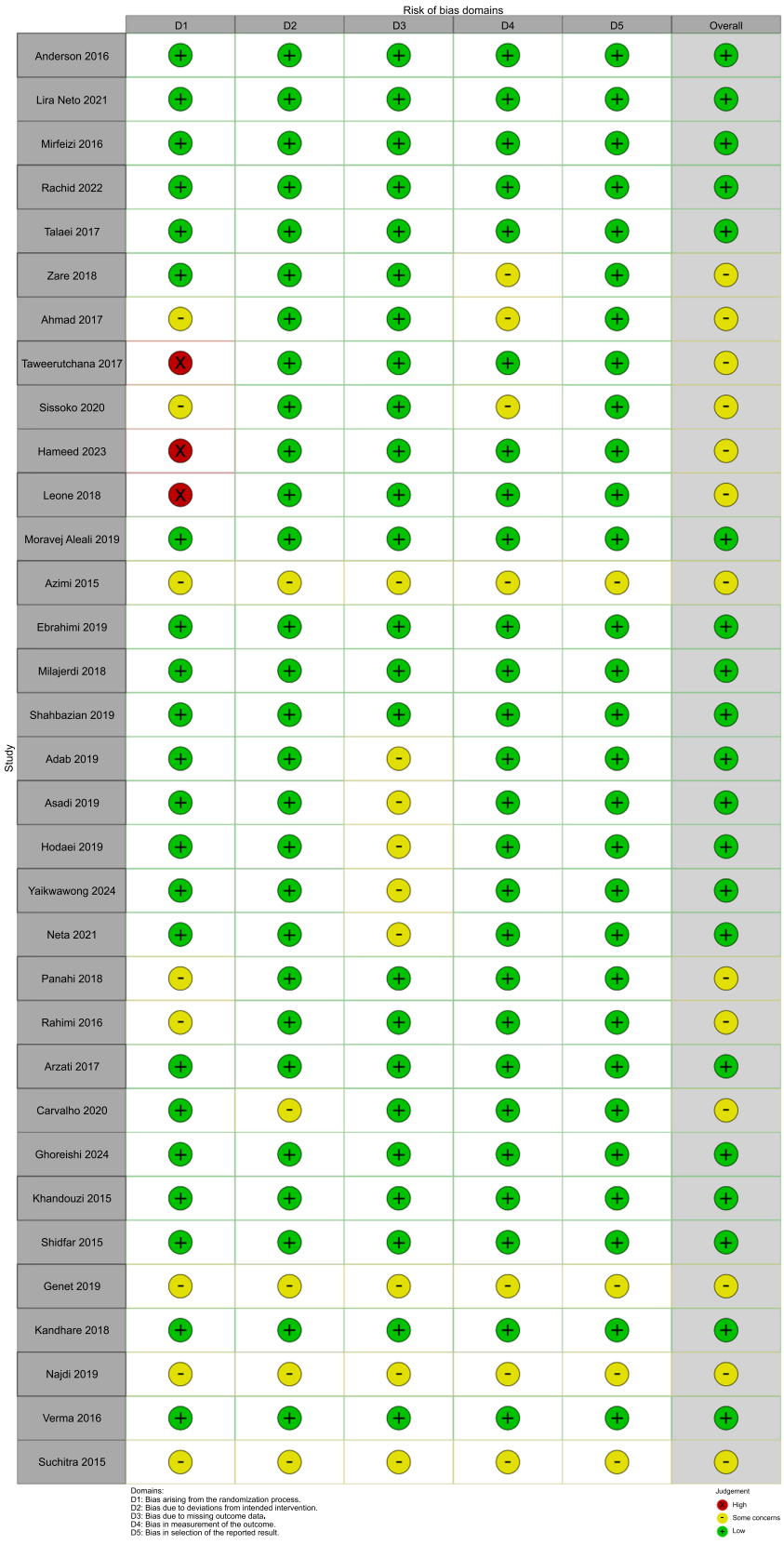

Fig. (2). Risk of bias graph.

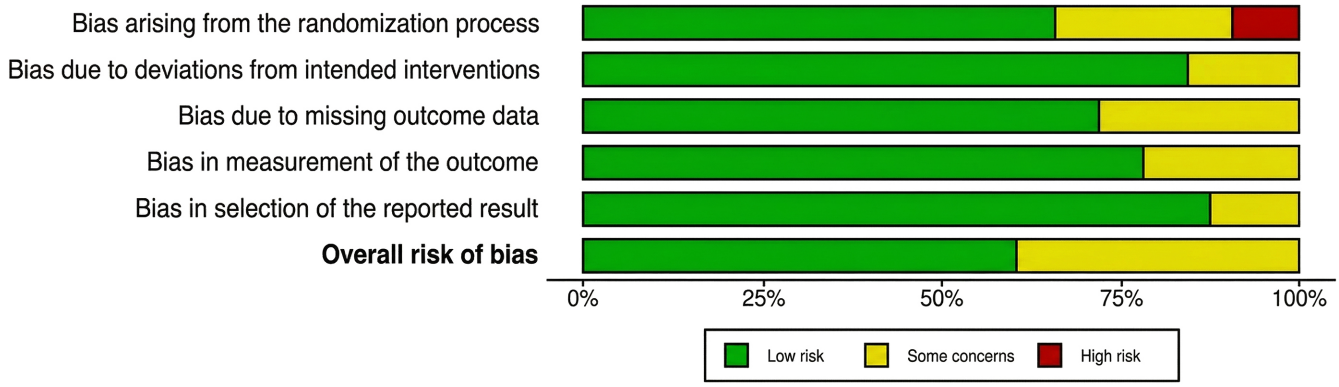

Fig. (3). Risk of bias summary.

4. DISCUSSION

The study aimed to comprehensively investigate the efficacy of herbal therapies in controlling T2DM. Various included studies provided evidence that cinnamon, fenugreek, ginger, and saffron can improve FBG and HbA1c levels, increase insulin sensitivity, and lower cholesterol levels. However, others failed to show significant improvements in glycaemic management. Studies have suggested that cinnamon supplementation can significantly improve FBG and HbA1c levels, making it a valuable potential adjuvant for regulating blood glucose levels in individuals with T2DM [21, 53, 54]. Additional work has demonstrated its potential to boost insulin sensitivity and lower cholesterol levels, contributing to overall better metabolic health [53]. However, previous studies have also reported conflicting outcomes, finding no significant influence in these measures [24]. Factors contributing to variability include differences in study design, cinnamon dosage, intervention duration, and baseline characteristics of the study population.

Curcumin administration, particularly in nano-formulations or when mixed with piperine, has been suggested to provide significant improvements in FBG and HbA1c levels, demonstrating its potential as a valuable adjuvant in regulating blood glucose levels in T2DM patients. Other evidence suggests it can boost β-cell activity and lower insulin resistance, suggesting that it can strengthen the body's ability to produce and respond to insulin. Additionally, curcumin has been proven to improve adiponectin levels, which are good for metabolic health, as they play a critical role in regulating glucose levels and breaking down fatty acids. Previous studies have also reported positive effects of curcumin on glycaemic control and metabolic health; nano-curcumin has been shown to significantly decrease HbA1c, FBG, and triglyceride levels in diabetic patients, and to prevent high-fat diet-induced insulin resistance and obesity by attenuating lipogenesis in the liver and inflammatory pathways in adipocytes [32, 55, 56]. Overall, curcumin shows potential as an adjuvant herb for glycaemic control and metabolic health.

Reductions in FBG and HbA1c levels with fenugreek seed powder intake indicate a favourable effect on glycaemic control [57]. Fenugreek seed powder also demonstrated significant changes in lipid profiles, lowering TC, LDL-C, and TG levels while elevating HDL-C; each of these is beneficial to cardiovascular health. Previous studies have indicated similar effects on lipid profiles of hypercholesterolemic T2DM patients [58]. Other studies have indicated more significant results, such as Shabil *et al.*'s (2023) systematic review, which found a drop in FBG and HbA1c levels with fenugreek intake, although results varied among trials [59]. Fenugreek seed powder shows potential for improving glycaemic management and lipid profiles, with more consistent results for cholesterol-lowering benefits. However, the diversity in glycaemic control outcomes underscores the need for additional standardised studies to find the ideal circumstances for its administration.

Ginger supplementation has been demonstrated to improve glycaemic management, lipid profiles, and antioxidant capacity, and reduce oxidative stress in persons with T2DM. Studies have demonstrated that ginger can dramatically lower FBG, HbA1c, and LDL cholesterol levels, suggesting it can be effective for regulating blood glucose levels and improving lipid profiles [38]. Additionally, ginger supplementation has been demonstrated to boost antioxidant capacity and lower oxidative stress markers, such as MDA. Previous studies have also indicated comparable advantages, showing significantly lowered TC, LDL-C, and TG levels [60]. However, studies have shown inconsistent results on oxidative stress, with some indicating considerable reduction in inflammation and oxidative stress indicators [61, 62].

Research on the impact of *Moringa oleifera* on glycaemic management has shown inconsistent results. Some studies have observed decreases in postprandial glucose levels, suggesting that Moringa may help regulate blood sugar levels after meals [63-65]. However, Taweerutchana *et al.* (2017) showed no significant effects on overall glycaemic measures, demonstrating variability in the efficiency of Moringa for blood glucose control [44]. *Moringa oleifera* has potential benefits for blood pressure control, as its leaf extract contains chemicals, including

flavonoids and potassium, which have antihypertensive properties [66]. Studies have demonstrated that Moringa leaf extracts have considerable free radical scavenging activity and can increase the body's antioxidant defences [67, 68].

Studies have demonstrated that saffron supplementation can enhance FBG and lipid profiles, potentially assisting T2DM patients in regulating blood glucose levels and improving lipid profiles. However, these studies also revealed no significant influence on inflammatory markers or oxidative stress, suggesting a limit to saffron's benefits in this regard. Previous studies have revealed similar positive effects of saffron supplementation on glycaemic control and lipid profiles [69, 70]. However, other studies have produced inconsistent results on inflammatory markers and oxidative stress, with some indicating favourable effects while others have no significant influence [50]. Abedi *et al.* (2023) revealed that saffron supplementation significantly decreased MDA and total oxidant status (TOS) levels while raising total antioxidant capacity (TAC) and glutathione peroxidase (GPx) levels [71].

5. LIMITATIONS OF THE STUDY

The systematic review and meta-analysis on herbal interventions for T2DM have some limitations, including heterogeneity across studies and varying doses and durations of treatment. The short length of many of the therapeutic interventions also restricts the ability to examine long-term effectiveness and safety. Limited evidence on safety and adverse effects was provided in many studies, further hindering evaluation, particularly of long-term safety. Several included studies were conducted with relatively small sample sizes, which limits the generalisability of the findings and increases the risk of statistical imprecision. In addition, the short duration of interventions in some studies may have been insufficient to adequately evaluate long-term effects and the sustainability of observed outcomes. These methodological limitations should be considered when interpreting the overall conclusions of this review. Future research employing larger, adequately powered samples and extended follow-up periods is warranted to validate and strengthen the existing evidence base.

CONCLUSION

This systematic review concluded that cinnamon supplementation significantly reduced FBG, HbA1c, and insulin sensitivity. Curcumin, particularly in nano-formulations or coupled with piperine, demonstrated substantial improvements in FBG, HbA1c, and β-cell activity. Fenugreek was beneficial in lowering lipid profiles, whereas ginger supplementation significantly lowered FBG, HbA1c, and LDL-C. Moringa lowered postprandial glucose levels, but had no significant effect on overall glycaemic control. Saffron enhanced FBG and lipid profiles but had no significant effect on inflammatory markers or oxidative stress.

Herbal therapies can be considered as supplementary therapies for conventional diabetic medications, particularly for individuals seeking natural options or those with mild to severe T2DM. Further research should focus on extended intervention durations and combination therapies.

AUTHOR'S CONTRIBUTIONS

The sole author conducted the entire work, including conceptualization, literature search, data extraction, analysis, manuscript writing, and final approval.

LIST OF ABBREVIATIONS

TC	=	Total Cholesterol
TG	=	Triglycerides
LDL-C	=	Low-Density Lipoprotein Cholesterol
HDL-C	=	High-Density Lipoprotein Cholesterol

CONSENT FOR PUBLICATION

Not applicable.

STANDARDS OF REPORTING

PRISMA guidelines and methodology were followed.

AVAILABILITY OF DATA AND MATERIALS

The data and supportive information is available within the article.

FUNDING

None.

CONFLICT OF INTEREST

The author declares no conflict of interest, financial or otherwise.

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SUPPLEMENTARY MATERIAL

PRISMA checklist is available as supplementary material on the publisher's website along with the published article.

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