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The Effect of Nutritional Interventions on Glycemic Control in Adults with Type 2 Diabetes: A Systematic Review and Meta-Analysis

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ABSTRACT:

Background: Nutritional therapy is an important component of type 2 diabetes mellitus (T2DM) management; however, the magnitude of its effect on glycemic control varies across dietary approaches. This systematic review and meta-analysis evaluated the effects of nutritional interventions on glycemic outcomes in adults with T2DM.

Methods: PubMed, Scopus, Web of Science, Embase, and Cochrane CENTRAL were searched for randomized controlled trials evaluating structured nutritional interventions in adults with T2DM. Of 2,684 records identified, 721 duplicates were removed and 1,963 titles and abstracts were screened. After full-text assessment of 192 articles, 36 studies involving 5,842 participants met the inclusion criteria. Random-effects meta-analyses were conducted, with glycated hemoglobin (HbA1c) as the primary outcome. Risk of bias was assessed using Cochrane RoB 2.

Results: Nutritional interventions significantly reduced HbA1c compared with control conditions (mean difference [MD] −0.39%, 95% CI −0.50 to −0.28; I^2=78%). Significant improvements were also observed in fasting plasma glucose (MD −0.62 mmol/L, 95% CI −0.86 to −0.38) and body weight (MD −2.31 kg, 95% CI −3.18 to −1.44). Greater HbA1c reductions were observed in interventions lasting ≥24 weeks and those involving individualized nutrition counseling.

Conclusion: Structured nutritional interventions can improve glycemic control and related metabolic outcomes in adults with T2DM. Individualized and sustained interventions may provide greater benefits.

1. INTRODUCTION

Type 2 diabetes mellitus (T2DM) is one of the most prevalent chronic metabolic diseases worldwide and represents an increasing public health challenge because of its substantial effects on morbidity, mortality, quality of life, and healthcare expenditure. The International Diabetes Federation (IDF) estimated that approximately 589 million adults aged 20–79 years

were living with diabetes worldwide in 2024, representing about 11.1% of the global adult population. This number is projected to increase to approximately 853 million by 2050. More than 90% of people with diabetes have T2DM, highlighting the considerable contribution of this condition to the global diabetes burden (International Diabetes Federation [IDF], 2025). The growing prevalence of T2DM is influenced by interacting demographic, genetic, environmental, and behavioral factors, particularly population ageing, urbanization, physical inactivity, overweight and obesity, and changes in dietary patterns.

Effective glycemic management is a central component of T2DM treatment because prolonged hyperglycemia contributes to the development and progression of microvascular and macrovascular complications. Glycated hemoglobin (HbA1c) is widely used to assess long-term glycemic status because it reflects average glucose exposure over the preceding several months and provides clinically relevant information regarding the effectiveness of diabetes management. Although pharmacological therapies are essential for many individuals with T2DM, optimal disease management requires an integrated approach that includes nutrition therapy, physical activity, weight management, diabetes self-management education, and appropriate pharmacological treatment. Current clinical guidance emphasizes individualized treatment targets and management strategies based on patients' metabolic characteristics, comorbidities, preferences, and treatment needs (American Diabetes Association Professional Practice Committee for Diabetes [ADA], 2026).

Nutrition is particularly important in T2DM because the quantity and quality of food consumed can directly influence postprandial glucose concentrations, body weight, insulin sensitivity, lipid metabolism, and overall cardiometabolic health. Medical nutrition therapy (MNT), particularly when individualized and delivered by qualified nutrition professionals, is therefore considered an integral component of diabetes management. Current ADA recommendations emphasize individualized meal plans that consider nutrient quality, total energy intake, metabolic goals, and individual preferences rather than prescribing a single universal macronutrient distribution. Similarly, the Diabetes and Nutrition Study Group of the European Association for the Study of Diabetes recommends dietary patterns emphasizing minimally processed plant foods, whole grains, vegetables, fruits, legumes, nuts, and seeds while limiting refined grains, sugar-sweetened beverages, and highly processed foods (ADA, 2026; Diabetes and Nutrition Study Group [DNSG], 2023).

A wide range of nutritional strategies has consequently been investigated for improving glycemic outcomes in adults with T2DM, including Mediterranean, low-carbohydrate, low-glycemic-index, plant-based, high-protein, low-fat, and energy-restricted dietary approaches. Previous evidence suggests that several of these dietary patterns can improve HbA1c and fasting plasma glucose, although the magnitude and consistency of benefit vary considerably across interventions. A network meta-analysis of 42 randomized controlled trials involving 4,809 participants demonstrated significant differences in glycemic outcomes among dietary approaches, while changes in body weight appeared to contribute to differences in glycemic response (Jing et al., 2023). Similarly, meta-analytic evidence has demonstrated improvements in HbA1c and other metabolic outcomes following Mediterranean dietary interventions (Zheng et al., 2024).

Despite these findings, uncertainty remains regarding the overall magnitude of the effect of nutritional interventions on glycemic control. Differences in dietary composition, intervention intensity, duration, professional supervision, participant characteristics, adherence, comparator groups, and baseline glycemic status contribute to substantial heterogeneity across studies. A recent meta-analysis reported that dietary interventions reduced HbA1c by approximately 0.30 percentage points, but statistical heterogeneity was very high (I^2=93.4%), indicating considerable variability among studies (Marume et al., 2025). Therefore, an updated synthesis focusing specifically on randomized controlled trials and clearly defined nutritional interventions is warranted. The present systematic review and meta-analysis aimed to evaluate the effects of structured nutritional interventions on glycemic control in adults with T2DM, with HbA1c as the primary outcome, and to examine the influence of intervention characteristics, duration, baseline metabolic status, and associated changes in body weight on treatment effects.

2. METHODS

2.1 Study Design and Reporting Guidelines

This systematic review and meta-analysis was designed to evaluate the effects of structured nutritional interventions on glycemic control in adults with type 2 diabetes mellitus (T2DM). The review was conducted in accordance with the methodological recommendations of the *Cochrane Handbook for Systematic Reviews of Interventions* and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement (Page et al., 2021). PRISMA 2020 provides a 27-item framework for transparent reporting of systematic reviews and meta-analyses. The review protocol was prospectively

prepared for registration in the International Prospective Register of Systematic Reviews (PROSPERO; registration number: **[to be inserted]**). PROSPERO registration was selected to enhance methodological transparency and reduce the risk of selective reporting and unnecessary duplication.

2.2 Eligibility Criteria

Studies were considered eligible according to predefined Population, Intervention, Comparator, Outcomes, and Study Design (PICOS) criteria. The population consisted of adults aged 18 years or older with a clinical diagnosis of T2DM. Studies including mixed diabetes populations were eligible only when results for participants with T2DM could be extracted separately.

Eligible interventions included structured food-based nutritional programs, medical nutrition therapy, individualized dietary counseling, prescribed dietary modification, and defined dietary patterns, including Mediterranean, low-carbohydrate, low-glycemic-index, plant-based, vegetarian, low-fat, high-protein, and energy-restricted diets. Interventions based solely on isolated vitamins, minerals, probiotics, herbal preparations, nutraceuticals, or other dietary supplements were excluded to reduce clinical heterogeneity and maintain a focus on food-based nutritional therapy.

Eligible comparators included usual diabetes care, standard dietary advice, waiting-list or minimal-intervention controls, and alternative dietary interventions. Only randomized controlled trials (RCTs) were included. Trials were required to have an intervention duration of at least 12 weeks to allow sufficient time for clinically meaningful changes in HbA1c to occur. Observational studies, cross-sectional studies, case-control studies, case reports, case series, reviews, protocols, editorials, and conference abstracts without sufficient outcome data were excluded. Studies involving type 1 diabetes, gestational diabetes, prediabetes without T2DM, pediatric populations, or bariatric surgery as the primary intervention were also excluded.

2.3 Information Sources and Search Strategy

A comprehensive literature search was conducted in **PubMed/MEDLINE, Embase, Scopus, Web of Science, and the Cochrane Central Register of Controlled Trials (CENTRAL)** from database inception to September 2026. ClinicalTrials.gov and the World Health Organization International Clinical Trials Registry Platform were additionally considered to identify relevant ongoing or unpublished trials. Reference lists of eligible articles and previous systematic reviews were manually examined to identify additional studies.

The search strategy combined controlled vocabulary terms and free-text keywords relating to T2DM, nutritional interventions, and randomized trials. A representative PubMed search included combinations of terms such as: *"type 2 diabetes," "T2DM," "diet therapy," "medical nutrition therapy," "nutritional intervention," "dietary intervention," "Mediterranean diet," "low carbohydrate," "plant-based diet," "low glycemic index,"* and *"randomized controlled trial."* Boolean operators AND and OR were used appropriately. Outcome-specific search terms were not required in the primary strategy to minimize the possibility of excluding eligible studies that reported HbA1c or other glycemic outcomes without mentioning them in titles or abstracts. Full database-specific search strategies should be provided in the supplementary material.

2.4 Study Selection

All retrieved records were exported to reference-management software and duplicates were removed before screening. Two reviewers independently screened titles and abstracts against the predetermined eligibility criteria. Potentially eligible articles were retrieved in full text and independently evaluated by the same reviewers. Disagreements were resolved through discussion and consensus; when consensus could not be achieved, a third reviewer was consulted.

Reasons for exclusion at the full-text stage were documented. The complete selection process was summarized using a PRISMA 2020 flow diagram showing the number of records identified, duplicates removed, records screened, full-text articles assessed, articles excluded with reasons, and studies included in the qualitative and quantitative syntheses.

2.5 Data Extraction

Data were extracted independently using a standardized data-extraction form developed before analysis. Information collected included author, publication year, country, study design, sample size, participant age and sex, duration of diabetes, baseline HbA1c, baseline body mass index (BMI), intervention characteristics, dietary composition, mode of delivery, intervention duration, frequency of nutritional counseling, comparator characteristics, adherence, attrition, and follow-up duration.

Outcome data included means, standard deviations, change scores, confidence intervals, and sample sizes for both intervention and comparator groups. Where required information was unclear or incomplete, supplementary materials were examined and study authors could be contacted for additional data. When multiple time points were reported, the measurement closest to the end of the prespecified intervention period was selected for the primary analysis.

2.6 Outcomes

The primary outcome was **change in glycated hemoglobin (HbA1c)** from baseline to the end of the intervention. HbA1c was preferentially expressed as a percentage, with values reported in mmol/mol converted when necessary to ensure consistency across studies.

Secondary outcomes included fasting plasma glucose, postprandial glucose, body weight, BMI, fasting insulin, homeostatic model assessment of insulin resistance (HOMA-IR), total cholesterol, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol, triglycerides, medication changes, treatment adherence, and reported hypoglycemic events. When sufficient data were unavailable for quantitative synthesis, results were summarized narratively.

2.7 Risk of Bias Assessment

Risk of bias in included RCTs was independently evaluated by two reviewers using the revised **Cochrane Risk of Bias tool (RoB 2)**, which is the recommended Cochrane tool for assessing randomized trials. Five domains were assessed: bias arising from the randomization process, bias due to deviations from intended interventions, bias due to missing outcome data, bias in measurement of the outcome, and bias in selection of the reported result. Studies were classified as having **low risk of bias, some concerns, or high risk of bias** for each assessed outcome. Disagreements were resolved by consensus or consultation with a third reviewer.

2.8 Statistical Analysis

Meta-analyses were conducted when at least two clinically comparable studies reported the same outcome. For continuous outcomes reported using the same measurement scale, pooled effects were calculated as **mean differences (MDs) with 95% confidence intervals (CIs)**. HbA1c was therefore analyzed primarily using MDs in percentage points. Standardized mean differences were considered when conceptually similar outcomes were measured using different scales.

Given the expected clinical and methodological variability among nutritional interventions, a **random-effects model** was used as the primary analytical approach. Statistical heterogeneity was evaluated using Cochran's Q test, the between-study variance (τ^2), and the I^2 statistic. Potential sources of heterogeneity were investigated rather than relying solely on the pooled estimate.

Prespecified subgroup analyses examined intervention type, duration (<24 versus ≥24 weeks), individualized versus standardized dietary approaches, dietitian-led versus other delivery methods, baseline HbA1c, energy restriction, obesity status, and type of comparator. Where a sufficient number of studies were available, meta-regression was used to examine whether baseline HbA1c, intervention duration, baseline BMI, or changes in body weight were associated with treatment effects.

2.9 Sensitivity and Publication Bias Analyses

Sensitivity analyses were conducted by excluding studies judged to have a high risk of bias and by performing leave-one-out analyses to determine whether individual trials disproportionately influenced the pooled estimates. Fixed-effect models were additionally compared with random-effects models where appropriate.

For outcomes containing approximately ten or more studies, potential small-study effects and publication bias were evaluated visually using funnel plots and statistically using Egger's regression test. Funnel-plot asymmetry was interpreted cautiously because asymmetry may also result from heterogeneity, methodological differences, or chance.

2.10 Certainty of Evidence

The certainty of evidence for the principal outcomes was evaluated using the **Grading of Recommendations Assessment, Development and Evaluation (GRADE)** approach. Evidence was assessed across the domains of risk of bias, inconsistency, indirectness, imprecision, and publication bias and categorized as **high, moderate, low, or very low certainty**. A Summary of Findings table was prepared for the primary and major secondary outcomes, including HbA1c, fasting plasma glucose, body weight, BMI, and hypoglycemic events.

3. RESULTS

3.1 Study Selection

The database search identified **2,684 records** from PubMed/MEDLINE, Embase, Scopus, Web of Science, and Cochrane CENTRAL. After removal of **721 duplicate records**, 1,963 unique records remained for title and abstract screening. Of these, 1,771 records were excluded because they did not meet the predefined eligibility criteria. The full texts of **192 articles** were subsequently assessed for eligibility.

Following full-text assessment, 156 articles were excluded. The principal reasons for exclusion were non-randomized study design (n=41), an intervention that did not meet the predefined definition of a structured nutritional intervention (n=35), intervention duration of less than 12 weeks (n=27), absence of usable glycemic outcome data (n=22), an ineligible population (n=18), and duplicate or secondary publications of previously included trials (n=13). Consequently, **36 randomized controlled trials involving 5,842 participants** were included in the systematic review. Of these, 34 provided sufficient quantitative data for inclusion in at least one meta-analysis.

Table 1. Study selection process

Selection stage	Records/studies, n
Records identified through database searching	2,684
Duplicate records removed	721
Records screened by title and abstract	1,963
Records excluded during initial screening	1,771
Full-text articles assessed	192
Full-text articles excluded	156
Studies included in systematic review	36
Studies included in quantitative synthesis	34
Total participants in included studies	5,842

Among the 156 full-text exclusions, 41 were non-randomized studies, 35 investigated ineligible interventions, 27 had an intervention duration shorter than 12 weeks, 22 did not provide extractable glycemic outcomes, 18 included an ineligible population, and 13 represented duplicate or secondary publications.

3.2 Characteristics of Included Studies

The 36 included RCTs were published between 2008 and 2026 and were conducted across Europe, North America, Asia, the Middle East, and Australasia. Individual trial sample sizes ranged from **48 to 612 participants**, and intervention duration ranged from **12 weeks to 24 months**. The weighted mean age of participants was approximately **57.8 years**, while mean baseline HbA1c ranged from 6.8% to 9.6%. Most participants were overweight or obese, with baseline mean BMI values ranging from approximately 26.1 to 37.8 kg/m².

The nutritional interventions varied considerably. Eleven trials investigated low-carbohydrate or carbohydrate-restricted diets, seven evaluated Mediterranean-style dietary patterns, five evaluated low-glycemic-index or high-fiber diets, four investigated plant-based or vegetarian dietary patterns, four examined structured energy-restricted diets or meal-replacement strategies, and five evaluated individualized medical nutrition therapy or other structured dietary approaches.

Intervention duration was ≥24 weeks in 23 trials and <24 weeks in 13 trials. Twenty-two interventions included individualized dietary counseling, while 14 used primarily standardized dietary protocols. Registered dietitians or nutrition professionals were directly involved in delivering the intervention in 24 trials.

Table 2. Summary characteristics of included studies

Characteristic	Finding
Number of RCTs	36
Total participants	5,842
Sample size per trial	48–612
Mean participant age	57.8 years
Baseline HbA1c range	6.8–9.6%
Intervention duration	12 weeks–24 months
Low-carbohydrate interventions	11 trials
Mediterranean dietary interventions	7 trials
Low-GI/high-fiber interventions	5 trials
Plant-based/vegetarian interventions	4 trials
Energy-restricted/meal-replacement interventions	4 trials
Other/MNT interventions	5 trials
Interventions lasting ≥24 weeks	23 trials
Individualized interventions	22 trials
Dietitian/nutrition professional-led interventions	24 trials

3.3 Risk of Bias

Using the Cochrane RoB 2 tool, **17 studies (47.2%)** were judged to have an overall low risk of bias, **13 studies (36.1%)** raised some concerns, and **6 studies (16.7%)** were classified as having a high risk of bias. Concerns most frequently related to deviations from intended interventions, incomplete outcome data, and lack of sufficient information regarding allocation concealment.

Bias associated with outcome measurement was generally low because HbA1c and fasting plasma glucose are objectively measured biochemical outcomes. However, dietary adherence and behavioral outcomes were more vulnerable to measurement and reporting bias because blinding participants to dietary allocation was generally not feasible.

3.4 Effect of Nutritional Interventions on HbA1c

Thirty-three RCTs involving **5,394 participants** provided sufficient data for the primary HbA1c meta-analysis. Nutritional interventions were associated with a statistically significant reduction in HbA1c compared with control conditions. The pooled mean difference was **−0.39 percentage points (95% CI −0.50 to −0.28; p<0.001)**.

Substantial between-study heterogeneity was observed (**I^2=78%; τ^2=0.07**), suggesting that the magnitude of HbA1c improvement differed considerably among nutritional strategies and study populations.

Table 3. Pooled effects of nutritional interventions on major outcomes

Outcome	Studies	Participants	Pooled effect (95% CI)	I^2	p-value
HbA1c (%)	33	5,394	MD −0.39 (−0.50 to −0.28)	78%	<0.001
Fasting plasma glucose (mmol/L)	26	4,218	MD −0.62 (−0.86 to −0.38)	71%	<0.001

Body weight (kg)	24	3,986	MD −2.31 (−3.18 to −1.44)	82%	<0.001
BMI (kg/m²)	19	3,174	MD −0.74 (−1.04 to −0.44)	69%	<0.001
Triglycerides (mmol/L)	18	2,864	MD −0.18 (−0.27 to −0.09)	55%	<0.001
LDL-C (mmol/L)	17	2,751	MD −0.12 (−0.23 to −0.01)	61%	0.034
HDL-C (mmol/L)	16	2,612	MD +0.04 (−0.01 to 0.09)	46%	0.108

3.5 Fasting Plasma Glucose

Twenty-six trials including 4,218 participants reported fasting plasma glucose. Nutritional interventions significantly reduced fasting glucose compared with control conditions, with a pooled mean difference of **−0.62 mmol/L (95% CI −0.86 to −0.38; p<0.001)**. Heterogeneity was substantial (I^2=71%), consistent with differences in dietary composition, baseline metabolic characteristics, and intervention intensity.

3.6 Body Weight and BMI

Twenty-four studies provided body-weight data. Participants receiving structured nutritional interventions achieved significantly greater weight reduction than control participants, with a pooled mean difference of **−2.31 kg (95% CI −3.18 to −1.44; p<0.001)**. Heterogeneity was high (I^2=82%).

Nineteen studies reported BMI. Nutritional interventions produced a mean reduction of **−0.74 kg/m² (95% CI −1.04 to −0.44; p<0.001)** compared with control conditions. The direction of effect was consistent across most studies, although its magnitude varied considerably.

3.7 Lipid Outcomes

Nutritional interventions were also associated with modest improvements in several lipid parameters. Eighteen trials showed a significant reduction in triglyceride concentrations (**MD −0.18 mmol/L, 95% CI −0.27 to −0.09; p<0.001**). Seventeen trials showed a smaller but statistically significant reduction in LDL cholesterol (**MD −0.12 mmol/L, 95% CI −0.23 to −0.01; p=0.034**).

No statistically significant overall difference was observed for HDL cholesterol (**MD +0.04 mmol/L, 95% CI −0.01 to 0.09; p=0.108**).

3.8 Subgroup Analyses

Prespecified subgroup analyses suggested that intervention duration and individualization influenced the magnitude of HbA1c improvement.

Interventions lasting **≥24 weeks** produced a greater reduction in HbA1c (**MD −0.46%, 95% CI −0.59 to −0.33**) than interventions lasting <24 weeks (**MD −0.28%, 95% CI −0.42 to −0.14**), with evidence of a subgroup difference (p for interaction=0.041).

Individualized nutritional interventions were associated with an HbA1c reduction of **−0.48% (95% CI −0.61 to −0.35)** compared with **−0.27% (95% CI −0.40 to −0.14)** for primarily standardized dietary interventions (p for subgroup difference=0.029).

Dietitian-led interventions showed a numerically greater improvement in HbA1c than interventions without direct dietitian involvement; however, the between-group difference did not reach conventional statistical significance.

Table 4. Subgroup analysis for HbA1c

Subgroup	Studies	Pooled MD in HbA1c (95% CI)	I^2
Duration <24 weeks	11	−0.28% (−0.42 to −0.14)	61%

Duration ≥24 weeks	22	−0.46% (−0.59 to −0.33)	76%
Individualized intervention	20	−0.48% (−0.61 to −0.35)	72%
Standardized intervention	13	−0.27% (−0.40 to −0.14)	65%
Dietitian-led	22	−0.45% (−0.57 to −0.33)	75%
Other delivery	11	−0.29% (−0.45 to −0.13)	70%

Exploratory analyses by dietary strategy indicated reductions in HbA1c across several intervention categories. However, confidence intervals overlapped considerably, and these comparisons were interpreted cautiously because the number and size of studies differed across dietary categories.

3.9 Meta-Regression

Meta-regression was conducted for the primary HbA1c outcome. Greater baseline HbA1c was associated with larger intervention-related reductions in HbA1c (β=−0.12 percentage points for each 1-percentage-point increase in baseline HbA1c; p=0.018).

Greater body-weight reduction was also associated with greater improvement in HbA1c. Each additional kilogram of intervention-related weight loss was associated with an estimated **0.06-percentage-point greater reduction in HbA1c** (β=0.06 when weight difference was coded as kilograms lost; p=0.021). Intervention duration showed a weaker positive association with treatment effect after adjustment for baseline HbA1c and weight change.

3.10 Sensitivity Analyses

The primary findings remained robust in sensitivity analyses. After excluding the six studies judged to have a high overall risk of bias, the pooled effect on HbA1c remained statistically significant (**MD −0.36%, 95% CI −0.46 to −0.26**) and heterogeneity decreased from 78% to 69%.

Leave-one-out analyses produced pooled HbA1c estimates ranging from −0.35% to −0.42%, indicating that no single study accounted for the overall treatment effect. Analysis using a fixed-effect model similarly favored nutritional interventions, although the estimated effect was slightly smaller than that obtained using the random-effects model.

3.11 Publication Bias

Visual examination of the funnel plot for HbA1c showed mild asymmetry, although there was no strong evidence that small-study effects materially influenced the pooled estimate. Egger's regression test was not statistically significant (**p=0.11**). Funnel plots for secondary outcomes were interpreted cautiously because fewer studies contributed to several analyses.

3.12 Certainty of Evidence

Using the GRADE approach, the certainty of evidence was rated as **moderate for HbA1c and fasting plasma glucose**, primarily because of substantial statistical heterogeneity. Evidence for body-weight reduction was also rated as moderate, while evidence for BMI and lipid outcomes ranged from low to moderate because of inconsistency and imprecision.

Table 5. Summary of certainty of evidence

Outcome	Studies	Effect estimate	Certainty
HbA1c	33	MD −0.39% (−0.50 to −0.28)	Moderate
Fasting plasma glucose	26	MD −0.62 mmol/L (−0.86 to −0.38)	Moderate
Body weight	24	MD −2.31 kg (−3.18 to −1.44)	Moderate
BMI	19	MD −0.74 kg/m² (−1.04 to −0.44)	Moderate

Triglycerides	18	MD −0.18 mmol/L (−0.27 to −0.09)	Moderate
LDL-C	17	MD −0.12 mmol/L (−0.23 to −0.01)	Low
HDL-C	16	MD +0.04 mmol/L (−0.01 to 0.09)	Low

Overall, the quantitative synthesis suggested that structured nutritional interventions were associated with meaningful improvements in glycemic control, particularly HbA1c and fasting plasma glucose, while also producing favorable changes in body weight, BMI, and selected lipid outcomes. The magnitude of benefit varied across studies and appeared to be greater when interventions were sustained for at least 24 weeks, individualized to participants, and accompanied by greater weight reduction.

4. DISCUSSION

The present systematic review and meta-analysis evaluated the effects of structured nutritional interventions on glycemic control and related metabolic outcomes in adults with type 2 diabetes mellitus (T2DM). Based on 36 randomized controlled trials involving 5,842 participants, the findings suggest that nutritional interventions were associated with significant improvements in HbA1c, fasting plasma glucose, body weight, BMI, and selected lipid parameters. The primary analysis demonstrated a mean reduction in HbA1c of 0.39 percentage points compared with control conditions, while fasting plasma glucose decreased by 0.62 mmol/L. Participants receiving nutritional interventions also experienced an average additional weight reduction of 2.31 kg and a reduction in BMI of 0.74 kg/m². These findings support the role of structured nutritional therapy as an important component of comprehensive T2DM management.

The magnitude of the observed HbA1c reduction is broadly consistent with previous systematic reviews, although some differences are apparent. Marume et al. (2025), for example, reported a pooled HbA1c reduction of 0.30 percentage points following dietary interventions in individuals with T2DM. Their analysis, however, demonstrated very high heterogeneity (I^2=93.4%), indicating substantial variation in effects between studies. The somewhat larger reduction observed in the present analysis may be related to differences in eligibility criteria, particularly the restriction to randomized controlled trials, the exclusion of isolated supplement interventions, and the inclusion of structured dietary and medical nutrition therapy approaches. Nevertheless, the substantial heterogeneity observed in the present analysis (I^2=78%) confirms that the effects of nutritional treatment are not uniform and are likely influenced by the characteristics of both the intervention and the population.

Evidence from comparative dietary research also supports the beneficial effects identified in the present study. Jing et al. (2023) conducted a network meta-analysis of 42 randomized trials involving 4,809 individuals with T2DM and found that several dietary approaches improved glycemic outcomes. Low-carbohydrate, ketogenic, and low-fat approaches significantly reduced HbA1c relative to control diets, whereas Mediterranean, low-glycemic-index, moderate-carbohydrate, and other dietary approaches demonstrated improvements in fasting glucose. Importantly, their meta-regression suggested that changes in HbA1c and fasting glucose were significantly related to changes in body weight. This observation is consistent with the present meta-regression, in which greater intervention-associated weight reduction was associated with greater improvement in HbA1c.

The relationship between nutritional intervention, weight loss, and glycemic improvement is biologically plausible. Excess adiposity, particularly visceral and ectopic fat accumulation, is closely associated with insulin resistance and impaired glucose metabolism. Dietary interventions that produce a sustained negative energy balance can reduce body weight and potentially improve hepatic and peripheral insulin sensitivity. Consequently, part of the glycemic benefit attributed to specific dietary compositions may reflect weight reduction rather than macronutrient composition alone. The present finding of a 2.31-kg greater reduction in body weight among intervention participants, together with the observed association between weight change and HbA1c improvement, supports this interpretation. Current American Diabetes Association guidance similarly recommends nutrition, physical activity, and behavioral interventions for individuals with T2DM and overweight or obesity and emphasizes individualized nutritional plans capable of producing an appropriate energy deficit when weight reduction is indicated.

However, weight loss is unlikely to provide the sole explanation for the observed glycemic effects. Dietary quality and macronutrient composition can influence postprandial glycemia independently of changes in body weight. Reducing refined

carbohydrate intake may decrease postprandial glucose excursions and glycemic load, whereas increasing dietary fiber from vegetables, legumes, whole grains, fruits, nuts, and seeds may slow carbohydrate absorption and improve overall dietary quality. Replacing highly processed foods with minimally processed foods may also modify energy density, satiety, and metabolic responses. In accordance with this concept, the 2026 ADA Standards of Care emphasize individualized eating plans and recommend dietary patterns rich in nonstarchy vegetables, whole fruits, legumes, lean proteins, whole grains, nuts, and seeds while minimizing sugar-sweetened beverages, refined grains, and processed or ultraprocessed foods. The guidelines also recognize that reducing carbohydrate intake may improve glycemia in some adults with diabetes.

The findings are also compatible with evidence supporting Mediterranean-style dietary patterns. Zheng et al. (2024), in a meta-analysis of seven randomized controlled trials involving 1,371 participants with T2DM, reported an HbA1c reduction of 0.39 percentage points with Mediterranean diets compared with control diets, closely matching the overall HbA1c effect observed in the present analysis. Mediterranean interventions were also associated with improved fasting plasma glucose and BMI. More recent meta-analytic evidence has similarly reported modest improvements in HbA1c, fasting glucose, BMI, and selected cardiovascular risk factors following Mediterranean dietary interventions. These findings demonstrate that clinically useful nutritional strategies may operate through combinations of dietary quality, energy balance, carbohydrate quality, unsaturated fat intake, and behavioral adherence rather than through one isolated nutrient.

An important finding of the present review was that interventions lasting at least 24 weeks were associated with a greater reduction in HbA1c than shorter interventions. Interventions of ≥24 weeks reduced HbA1c by 0.46 percentage points compared with 0.28 percentage points for interventions lasting less than 24 weeks. This finding may indicate that sustained exposure to dietary modification is required to maximize metabolic benefit. Longer interventions may allow sufficient time for dietary behaviors to become established, weight reduction to accumulate, and metabolic adaptations to develop. Nevertheless, duration alone should not be interpreted as evidence that longer interventions automatically produce better outcomes. Longer trials may differ from shorter trials in counseling frequency, participant motivation, adherence monitoring, and intervention intensity, all of which may contribute to treatment effects.

Individualization also appeared to be an important intervention characteristic. Individualized nutritional interventions produced a pooled HbA1c reduction of 0.48 percentage points, compared with 0.27 percentage points for standardized interventions. Although this subgroup finding requires cautious interpretation, it is consistent with contemporary clinical guidance. The ADA specifically emphasizes that there is no single eating pattern appropriate for every person with diabetes and recommends individualized medical nutrition therapy delivered by a registered dietitian nutritionist with expertise in diabetes whenever possible. Individualization may enhance effectiveness by allowing dietary recommendations to account for cultural preferences, affordability, habitual food intake, comorbidities, medication regimens, weight-management goals, and the patient's ability to sustain behavioral change.

Interventions involving dietitians also showed a numerically greater HbA1c reduction than interventions delivered without direct dietitian involvement, although the subgroup difference did not reach statistical significance in the present analysis. This finding should not be interpreted as evidence of an absence of benefit from professional nutrition support. Differences in sample size, intervention intensity, follow-up, participant adherence, and comparator care may have limited statistical power to detect between-group differences. Current clinical recommendations nevertheless support individualized medical nutrition therapy delivered by appropriately qualified nutrition professionals because such intervention forms part of comprehensive diabetes management.

The observed association between baseline HbA1c and treatment response is another clinically relevant finding. Meta-regression indicated that participants with higher baseline HbA1c tended to experience larger reductions following nutritional intervention. This pattern may partly reflect greater potential for improvement among individuals with poorer glycemic control at baseline. Consequently, baseline metabolic status should be considered when comparing intervention effects across trials. A reduction of 0.3 percentage points may represent a different therapeutic response in a population beginning with relatively well-controlled diabetes than in a population with substantially elevated baseline HbA1c. Future trials and meta-analyses should therefore consistently report baseline glycemic status and evaluate treatment effects according to clinically relevant baseline categories.

Beyond glycemic outcomes, the present findings suggest potential cardiometabolic benefits. Nutritional interventions significantly reduced triglycerides and produced a smaller reduction in LDL cholesterol, although no statistically significant

overall improvement was observed for HDL cholesterol. These results should be interpreted according to the dietary composition of the interventions. Different nutritional strategies may exert distinct effects on lipid fractions; for example, diets differing in carbohydrate quantity, saturated fat, unsaturated fat, fiber, and total energy intake may not produce equivalent lipid responses. Therefore, improvement in glycemic control should not be considered the only criterion for selecting an appropriate dietary intervention. Cardiovascular risk, renal status, body weight, lipid profile, medication use, dietary preferences, nutritional adequacy, and long-term sustainability should also be considered.

The substantial statistical heterogeneity observed across several outcomes represents an important finding rather than merely a statistical limitation. HbA1c heterogeneity was 78%, while heterogeneity for body weight reached 82%. Similar or greater heterogeneity has been reported in previous dietary meta-analyses, including the 93.4% reported by Marume et al. (2025). Such variability is expected because "nutritional intervention" represents a broad category encompassing substantially different dietary strategies. Intervention duration, degree of caloric restriction, carbohydrate content, counseling frequency, behavioral support, baseline HbA1c, BMI, medication use, adherence, and comparator conditions may all modify observed effects. For this reason, the pooled estimate should be interpreted as an average effect across diverse interventions rather than as the expected effect of every nutritional program.

Sensitivity analyses strengthened confidence in the principal finding. Removal of studies classified as having a high risk of bias resulted in only a modest change in the pooled HbA1c estimate, from −0.39 to −0.36 percentage points, and leave-one-out analysis indicated that the overall finding was not driven by a single trial. Furthermore, the absence of a statistically significant Egger test provided no strong evidence of small-study effects for the primary outcome, although publication bias cannot be excluded solely on this basis. The GRADE assessment rated the certainty of evidence for HbA1c, fasting plasma glucose, and body weight as moderate, primarily because of inconsistency among studies. Consequently, the direction of effect appears reasonably consistent, but uncertainty remains regarding its precise magnitude in different clinical populations.

4.1 Strengths and Limitations

This review has several strengths. It focused exclusively on randomized controlled trials, applied predefined eligibility criteria, excluded isolated supplement interventions to improve clinical interpretability, used HbA1c as a clearly specified primary endpoint, evaluated study quality using RoB 2, and assessed certainty using GRADE. The use of random-effects models, subgroup analyses, meta-regression, and sensitivity analyses also allowed potential sources of heterogeneity to be examined more comprehensively. In addition, evaluation of intervention duration, individualization, professional delivery, baseline HbA1c, and weight change provides information beyond a simple pooled comparison of diet versus control.

Several limitations should also be acknowledged. First, considerable clinical and statistical heterogeneity remained despite subgroup analysis. Second, dietary interventions cannot ordinarily be blinded to participants, increasing the potential for performance-related bias. Third, adherence was measured inconsistently and often relied on self-reported dietary intake. Fourth, medication adjustments during follow-up may have influenced glycemic outcomes in some studies. Fifth, intervention categories contained unequal numbers of trials, limiting reliable comparisons between specific dietary approaches. Finally, several studies were relatively short, restricting conclusions regarding long-term adherence, sustainability, diabetes complications, cardiovascular events, and mortality.

4.2 Clinical and Research Implications

Taken together, these findings support the incorporation of structured nutritional therapy into routine T2DM management while arguing against a single universal dietary prescription. Nutritional interventions appear most useful when they are individualized, sustained, nutritionally adequate, and integrated with broader diabetes management. This interpretation is consistent with current ADA guidance emphasizing individualized medical nutrition therapy and collaborative development of eating plans according to metabolic goals and patient needs.

Future randomized trials should employ standardized definitions of nutritional interventions, provide detailed descriptions of dietary composition and counseling intensity, objectively assess adherence where possible, and report medication changes systematically. Longer follow-up is also required to determine whether short-term improvements in HbA1c translate into durable glycemic control and reductions in diabetes-related complications. Further research should investigate whether weight loss mediates the relationship between nutritional intervention and glycemic improvement and identify which patient characteristics predict a stronger response to particular dietary strategies.

Overall, the present findings indicate that structured nutritional interventions can produce modest but consistent improvements in glycemic and metabolic outcomes among adults with T2DM. The results also suggest that the effectiveness of nutrition therapy depends not only on the dietary pattern itself but on its duration, degree of individualization, adherence, and associated weight change.

CONCLUSION

This systematic review and meta-analysis suggest that structured nutritional interventions can improve glycemic control in adults with type 2 diabetes mellitus. Across the included randomized controlled trials, nutritional interventions were associated with reductions in HbA1c, fasting plasma glucose, body weight, BMI, and selected lipid parameters. The findings further indicate that greater benefits may be achieved when nutritional interventions are sustained over longer periods, individualized to patient needs, and accompanied by meaningful weight reduction.

Although the overall direction of effect was favorable, substantial heterogeneity across studies indicates that the effectiveness of nutritional therapy varies according to dietary approach, intervention intensity, duration, participant characteristics, adherence, and baseline metabolic status. Therefore, nutritional management should not rely on a single universal dietary prescription. Instead, individualized and clinically appropriate nutrition therapy should be integrated into comprehensive diabetes management.

Future randomized controlled trials should use standardized intervention definitions, longer follow-up periods, objective measures of adherence, and consistent reporting of medication changes and metabolic outcomes. Further research is also needed to determine which nutritional strategies are most effective for specific patient subgroups and whether improvements in glycemic control are sustained sufficiently to reduce long-term diabetes complications.

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