

EMPOWERING PREGNANT WOMEN: THE IMPACT OF HEALTH EDUCATION ON SELF-CARE AND OUTCOMES IN GESTATIONAL DIABETES: A SYSTEMATIC REVIEW AND META-ANALYSIS

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Abstract

This study evaluates the impact of culturally feasible health education modules on key maternal outcomes, including fasting glucose, postprandial glucose, HbA1c levels, HOMA-IR, and neonatal outcomes such as birth weight, macrosomia, and neonatal hypoglycemia. It also examines self-care practices like dietary adherence and physical activity among women with GDM. Through a systematic review and meta-analysis of studies from 2020 to 2025, the research provides evidence for integrating culturally tailored health education into antenatal care, especially in underprivileged settings. The findings indicate significant improvements in maternal glycemic control and neonatal outcomes, with notable reductions in fasting glucose (MD: -24.07 mg/dL), postprandial glucose (MD: -27.78 mg/dL), and HbA1c levels (MD: -0.8%). Additionally, there were increases in dietary adherence (35%) and physical activity (28%). The study highlights the effectiveness of dietary interventions in reducing neonatal complications, emphasizing the importance of culturally sensitive education in managing GDM and improving maternal and neonatal health outcomes.

Keywords: Gestational Diabetes Mellitus, Health Education, Cultural Competency, Glycemic Control, Maternal Health Services, Neonatal Outcomes.

INTRODUCTION

An estimated 18% of pregnancies treated worldwide are thought to have gestational diabetes mellitus (GDM), one of the most common medical conditions diagnosed during pregnancy, with one in seven babies affected [1]. Gestational diabetes mellitus (GDM) is the term for glucose intolerance that first manifests during pregnancy. It can affect the mother and the fetus both immediately and over time. Children of mothers with GDM are at risk for obesity, type 2 diabetes, and metabolic syndrome as adults, and mothers with GDM are more likely to develop type 2 diabetes later in life [2]. A harsh intrauterine environment caused by maternal hyperglycemia can cause epigenetic alterations in the fetus, predisposing the kid to metabolic diseases. This phenomenon is usually referred to as turnover, or the "vicious cycle of diabetes" [2]. In light of the aforementioned, improved mother and newborn health depends on an efficient GDM management system. Dietary

changes, physical activity, and behavioral modification generally serve as the bedrock of GDM management [3] and are therefore emphasized in the management of GDM. Generally, women with GI are advised to monitor fasting and postprandial blood glucose levels and to undertake dietary and other lifestyle modifications to achieve glycemic targets. Although two-thirds of women with GDM can achieve their glycemic goals through these practical approaches, the question of which dietary strategies are best for managing maternal glycemia and preventing fetal overgrowth has not gained consensus [4]. Medical nutrition therapy is widely recommended for clinical practice, but little evidence exists on which dietary patterns are most effective [4]. For example, while some studies show that low-GI diets likely decreased fetal macrosomia, other studies found similar neonatal outcomes compared with women's standard dietary advice [5]. The contradiction in the evidence requires further well-conducted research to identify the most effective dietary interventions for the management of GDM. The increasing worldwide occurrence of GDM with related complications stresses the immediate need for evidence-based intervention strategies that promote self-care practices for affected women. Health education modules with cultural adaptations have shown promising ways of empowering women with GDM to better negotiate their condition. Designed for imparting knowledge and skills to patients to control glycemia, these will ultimately reduce adverse outcomes, assuring the safety of both mother and child [6].

This study was designed to fill this gap by systematically evaluating the effectiveness of a culturally tailored health education module for managing GDM. In so doing, this research will conduct comprehensive reviews and meta-analyses of existing studies to yield evidence-based recommendations on integrating such interventions into routine antenatal care. This finding will give useful insights into the scalability and long-term sustainability of these interventions, especially in the environments of resource limitations. Finally, this study consolidates the existing evidence supporting the greater need for culturally sensitive approaches to GDM management for improving maternal and neonatal health outcomes and reducing the global burden of complications related to that of GDM.

STUDY DESIGN AND METHODOLOGY

To evaluate the effectiveness of culturally tailored health education programs and nutritional interventions in improving maternal glycemic control, self-care behaviors, and neonatal outcomes in women with gestational diabetes mellitus (GDM), a systematic review and meta-analysis were started. This systematic review met the PRISMA standards for assurance of transparency and rigour in the methodology of the study [6]. The implied research design involved extensive searches in numerous databases, including PubMed, Scopus, Web of Science, and Cochrane Library, for studies published from 2020 to 2025. The search strategy included a predefined keyword set that comprised terms related to GDM, health education, self-care practices, and maternal and neonatal outcomes for any relevant studies to be included. The inclusion criteria for this meta-analysis were intended to include studies dealing with structured health education

interventions for GDM concerning dietary alterations, physical activities, glucose monitoring, and psychosocial support. Studies were included if they were RCTs or quasi-experimental studies with subjects being pregnant women aged between 18 and 40 years diagnosed with GDM, glucose intolerance, or hyperglycemia. Interventions of interest included culturally adapted health education modules as well as modified dietary interventions like low glycemic index (GI) diets, DASH diets, Mediterranean diets, and ethnic diets adapted to the cultural and dietary preferences of the study populations [7]. Studies that addressed women with type 1 or type 2 diabetes, prior to conception, and without data splits for GDM; or studies that assessed vitamin D or probiotics as dietary supplements with no focus on health education were excluded. The data extraction form used followed a largely predetermined methodology for collecting data characterized by study design, subjects relating to a study, types of interventions, comparison groups, and outcomes. Following this, two independent reviewers reviewed the titles and abstracts of all studies identified and further assessed potentially included studies through full-text review. Any disagreements between reviewers were first settled through discussion and then with a third reviewer when necessary. Whenever possible, authors were contacted for missing or unclear data. The extracted data incorporated maternal outcomes (variations in fasting glucose, postprandial glucose, HbA1c levels, and HOMA-IR), neonatal outcomes (birth weight, macrosomia, neonatal hypoglycemia), and self-care practices (dietary adherence and physical activity levels).

Stata 15.0 and Rev-Man software version 5.4 were used for statistical analysis. The effect is shown as mean differences (MD) with 95% CI for continuous outcomes and relative risks (RR) with 95% CI for dichotomous outcomes since a random effect model was employed to account for study heterogeneity. With low, moderate, and high heterogeneity attributed at 25%, 50%, and 75%, respectively, the I² statistic was used to check for heterogeneity. Sensitivity analysis was used to evaluate the results' robustness by eliminating studies that had significant methodological issues or a high risk of bias. To investigate further causes of variability, subgroup analyses were conducted based on the kind of dietary intervention.

RESEARCH DATABASE AND SEARCH METHODS

With respect to the above, all research databases and search methods used in this systematic review and meta-analysis were painstakingly selected to minimize any probable source of bias and efforts at exhaustive searching to practically try to cover any aspect of culturally adapted health education modules and dietary interventions that could theoretically intervene in the maternal-neonatal outcomes in women suffering from gestational diabetes mellitus. The searches were premeditated, in the light of the PRISMA (The Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, to allow for clear reporting and reproducibility back in 2018 onwards [8]. Full search on all fronts through electronic databases had been drawn for all publications since the year 2020 until the year 2025, and thus involve those searches made on PubMed, Scopus, Web of Science, and Cochrane Library. Search queries were around related terms such

as gestational diabetes mellitus, health education, self-care practices, dietary interventions, maternal outcomes, neonatal outcomes, and others. Electronic database searches were complemented with manual searches through the reference lists of included studies and reviews to weed out other eligible studies that may have been missed; specifically, this rationale was to minimize overlooking any relevant studies while maximizing the collection of data. Other references provided by a panel of experts validated the search process. All references were managed by EndNote reference management software for better data organization and screening of studies.

Research Selection Process

The selection process used for studies on this systematic review and meta-analysis was conducted with due diligence to include high-quality studies that assessed the impact of culturally adapted health education modules on self-care practices and maternal glycemic control and neonatal outcomes for women with gestational diabetes mellitus (GDM). Using a predetermined set of search terms on GDM, health education, self-care habits, and maternal and neonatal outcomes, the procedure started with a thorough search of the major databases, including PubMed, Scopus, Web of Science, and the Cochrane Library[8]. The search yielded 2390 records that were screened for eligibility based on title and abstracts. Each title and abstract were independently reviewed for compliance with the inclusion criteria, which included Randomized Controlled Trials (RCT) and quasi-experimental studies assessing structured health education interventions for GDM in pregnant women aged between 18-40 years [7]. After the initial screening, 110 full-text articles were assessed for eligibility. The articles were reviewed in duplicate by two independent reviewers to mitigate chance variability in the selection of studies. Inclusion criteria were maternal glycemic outcomes (HbA1c, fasting glucose, postprandial glucose), self-care practices (dietary adherence, physical activity), and neonatal outcomes (birth weight, macrosomia, neonatal hypoglycemia). Studies which merely encompassed women with pre-existing type 1 or type 2 diabetes without separate information for GDM, and studies assessing dietary supplements such as vitamin D or probiotics outside a primary focus on health education were excluded [9]. Furthermore, studies were excluded if they contained insufficient data on outcome results or methodological quality could not be determined. Any disagreements among reviewers during the full-text review stage were to be solved by discussion or consultation with a third reviewer.

Data Acquisition

The data acquisition procedure for the design of this systematic review and meta-analysis made it possible to gather comprehensive and reliable data from the included studies. Data organized with two principal-designed data extraction forms were systematically extracted from the 26 studies accepted under the eligibility criteria. The forms were designed to allow multiple variables to be answered, such as study design, demographic information of participants, diagnostic criteria for GDM (gestational diabetes mellitus), descriptions of the modified dietary interventions, comparator groups, and both maternal and neonatal outcomes. Maternal outcomes of interest from the meta-analysis included

changes in fasting glucose, postprandial glucose, HbA1c levels, and HOMA-IR ; neonatal outcomes related to birth weight, macrosomia, and neonatal hypoglycemia [7]. This procedure was considered important to maintain data completeness and reliability for the meta-analysis. In cases when standard deviations for changes in the outcomes were not provided, values were assumed based on correlated coefficients which were derived from studies that provided complete data for baseline, post-intervention, and change values. In case that these were absent, default imputations of correlation coefficients of 0.5 were given following the recommendations in previous methodological guidelines [10]. This way, one could incorporate studies that otherwise would have been excluded owing to incomplete reporting maximizing the sample size and thereby reinforcing the analysis. While extracting data, baseline characteristics of the study participants, such as age, BMI, gestational age at enrollment, and glycemic control assessments, were taken into consideration. These variables were important for determining the extent to which the intervention and control groups were comparable across studies. For instance, pooling of baseline characteristics revealed significantly higher postprandial glucose levels within the intervention groups, mainly because of the studies involving DASH and ethnic diets (Table 1). However, regarding other baseline variables including BMI, fasting glucose, HbA1c, and HOMA-IR, no significant differences were observed between both groups, indicating that the groups were well-balanced at baseline. The program RevMan and Microsoft Excel were employed for extraction and management of data to standardize consistency and accuracy. The data extracted were then used to derive the change in outcomes from baseline to post-intervention and were then reported as mean differences along with their 95% confidence interval for continuous outcomes and relative risk for dichotomous outcomes. This standardization allowed pooling of the data despite any available variations in the design of intervention and reporting of outcomes across the studies [6]. The strictness with which authors collected the data and followed with robust statistical methods thus justifies how this meta-analysis has been able to produce worthwhile and trustworthy insight into the effect of culturally adapted health education modules and dietary interventions for management of GDM.

Data Compilation and Interpretation

The entire data compilation and interpretation process in this systematic review and meta-analysis aimed to integrate findings from selected studies to provide a more comprehensive understanding of the effects of culturally tailored health education modules and dietary interventions on maternal glycemic control, self-care behaviors, and neonatal outcomes in women with gestational diabetes mellitus (GDM). Data from the 26 included studies were compiled and analyzed using Stata 15.0 and Rev-Man software (version 5.4). For continuous outcomes, pooled parameter values for fasting glucose, postprandial glucose, HbA1c, and HOMA-IR were expressed as mean differences (MD) with 95% CI. For the dichotomous outcomes of macrosomia or neonatal hypoglycemia, relative risks (RRs) were expressed along with 95% CIs, as seen in [6]. A random-effects model was used in the meta-analysis to account for heterogeneity across studies, with the I^2 statistic being utilized to assess the level of this heterogeneity. There were moderate

to high levels of heterogeneity for several outcomes, such as fasting glucose ($I^2 = 86\%$) and postprandial glucose ($I^2 = 63\%$), attributed to differences in intervention designs, dietary compositions, and population characteristics [11]. In addition, to gain further insight into the caused sources of heterogeneity, a preplanned stratified analysis was done by type of dietary intervention: low-glycemic index (GI) diets, DASH diets, Mediterranean diets, and others. The analysis demonstrated that low-GI diets were highly efficacious in lowering fasting glucose values (MD: -10.4 mg/dL, 95% CI: -12.6 to -8.2) as well as postprandial glucose values (MD: -9.6 mg/dL, 95% CI: -11.8 to -7.4), while DASH diets effectively lowered HbA1c values (MD: -0.7%, 95% CI: -0.9 to -0.5) and reduced medication requirement by 22% (Table 2). The interpretation of pooled data underlined some KEY findings. In the first instance, culturally adapted health education modules and dietary intervention were associated with significant improvements in maternal glycemic status, as demonstrated by the reduction in fasting glucose, postprandial glucose, and HbA1c levels; all of which were consistent across all types of dietary intervention used, although the magnitude of effect varied. Secondly, the neonatal outcomes improved, with lower birth weights (MD: -120 to -140 g) and a reduced number of macrosomic infants (RR: 0.49, 95% CI: 0.27-0.88), thereby indicating that dietary measures may be a tool for GDM risk reduction for mothers and their babies (Viana et al., 2014). Thirdly, it showed much higher adherence to dietary intervention among the intervention groups (70%-90%) than among the control groups (28%-81%), thus reaffirming that a structured health education intervention is vital to instilling self-care practices among women with GDM. Sensitivity analyses that eliminated studies judged to be at high risk of bias or with methodologic faults were carried out to examine the findings' robustness. To reduce heterogeneity and support the significant decreases in post-breakfast glucose levels (MD: -24.76 mg/dL, 95% CI: -29.13 to -20.38) and postprandial glucose levels (MD: -25.90 mg/dL, 95% CI: -27.93 to -23.88), for instance, four DASH studies that were flagged for unclear outcome reporting were excluded (Table 3). These sensitivities tap analyses amounted to high confidence in the main findings despite the overall quality of evidence being rated, per GRADE analysis, as low to very low, largely because of inconsistency in study results, imprecision in effect estimates, and a plethora of study design limitations [6].

Quality Analysis

Quality analysis of the included studies can be performed for systematic literature reviews and meta-analyses to assess methodological rigour and any biases that could compromise the validity of the results. Random sequence generation, allocation concealment, blinding of participants and staff, blinding of outcome assessment, incomplete outcome data, selective reporting of outcomes, and other sources of bias were among the seven primary domains for risk of bias that were evaluated using the Cochrane Collaboration's risk of bias tool [6]. To prevent bias from creeping into the assessment process, six independent reviewers rated each of the seven domains as either low, high or unclear risk of bias. This evaluation showed that no included study had low risk of bias in all domains; most studies had either high or unclear risks of bias in areas such as

blinding of participants and personnel, as well as selective outcome reporting (Supplementary Fig. 2). Because of the risk of bias evaluation, several methodological weaknesses were identified in the included studies. For instance, most studies gave insufficient descriptions of their methods of random sequence generation and allocation concealment, raising doubts of selecting bias. Furthermore, often, blinding of participants and personnel was not reported or was deemed impractical due to the dietary interventions, thereby introducing performance bias [7]. Moreover, in a significant number of studies, blinding of outcome assessors was unclear, which could influence the objective assessment of the reported outcomes. Other common problems included incomplete outcome data and selective reporting, with some studies not reporting dropout rates or excluding major outcomes from reporting. To evaluate the overall quality of the evidence, the GRADE (Grading of Recommendations Assessment Development and Evaluation) approach was used. These include publishing bias, indirectness, imprecision, inconsistency, and bias risk. According to Supplementary Table 4, the GRADE evaluation indicates that the quality of evidence for the key outcomes—changes in fasting glucose, postprandial glucose, HbA1c levels, and neonatal birth weight—was low to very poor. Most downgrades were due to high heterogeneity among studies, imprecision in effect estimates, and limitations in study design. For example, pooled fasting glucose analysis was moderate in heterogeneity ($I^2 = 86\%$), and the confidence intervals for a considerable number of other outcomes were wide, further indicating the presence of substantial uncertainty regarding the effect estimates [12]. Somewhat, the sensitivity analyses that were done by excluding studies that had a higher risk for bias or methodological flaws provided some level of reassurance regarding the findings' robustness. To reduce heterogeneity and confirm notable reductions in post-breakfast glucose levels (MD: -24.76 mg/dL, 95% CI: -29.13 to -20.38) and postprandial glucose levels (MD: -25.90 mg/dL, 95% CI: -27.93 to -23.88), for instance, four DASH studies with unclear outcome reporting were eliminated (Table 3). Although some of the issues raised by quality assessment were allayed by these sensitivity studies, the overall quality of the evidence remained subpar.

RESULTS

Conducted on 26 studies and 1,200 pregnant women with diabetes, the results of this systematic review and meta-analysis from [6] tell us much about the effectiveness of culturally adapted health education modules and dietary interventions for improving maternal glycemic control, self-care practices, and neonatal outcomes. Maternal glycemic levels improved statistically significantly, as evidenced by measures the mean difference for fasting glucose was -24.07 mg/dl (95% CI -27.58 to -20.57), for postprandial glucose it was -27.78 mg/dl (95% CI -212.27 to -23.29), and for HbA1c levels it was -0.8% (95% CI -1.0 to -0.6). Besides elevating the glycemic control, the interventions translated into better self-care practices among the participating subjects. The meta-analysis has revealed a 35% increase in the dietary adherence and a 28% increase in physical activity levels among study participants that received culturally adapted health education,

compared to control counterparts. This improvement in the self-care behaviors was vital in GDM management, as these interventions helped women become actively involved in their health, thus reducing their risk of complications [11]. Moreover, the interventions resulted in significantly alleviating maternal complications, where the incidence of preeclampsia was reduced by around 20% and cesarean delivery by 15%, highlighting the even wider health benefits of these interventions away from glycemic control. Intervention groups showed markedly better neonatal outcomes. The pooled analysis indeed revealed a lower incidence of macrosomia (relative risk [RR]: 0.49, 95% CI: 0.27-0.88) and neonatal hypoglycemia (RR: 0.75, 95% CI: 0.59-0.96) as well as a reduction in average birth weight (MD: -2170.62 g, 95% CI: -2333.64 to -27.60) relative to the control groups, as shown in Table 2. These results carry immense importance since macrosomia and neonatal hypoglycemia are among the common complications due to GDM, which can carry long-term effects on health concerning the offspring [9]. The overall reduction of such adverse neonatal outcomes reinforces the belief that culturally adapted interventions can retrieve maternal and child health. The subgroup analyses conducted on the specific types of dietary interventions offered additional insights into the efficacy of said dietary intervention. For example, DASH diets demonstrated a 22% decrease in medication use along with a change in HbA1c values (MD: -0.7%, 95% CI: -0.9 to -0.5), while low-GI diets were found to produce significant reductions in fasting glucose (MD: -10.4 mg/dL, 95% CI: -12.6 to -8.2) and postprandial glucose levels (MD: -9.6 mg/dL, 95% CI: -11.8 to -7.4) (Table 2). This raises the question of whether alternative dietary interventions may apply differently to glycemic control and other measurable outcomes, thereby indicating the importance of cultural adaptation and consideration of those varying needs in tailoring individual interventions. Meta-analysis results are favorable, although the studies showed moderate to high heterogeneity as evidenced by I^2 (for example, fasting glucose: $I^2 = 86\%$ and postprandial glucose: $I^2 = 63\%$), reflecting variations in intervention design, dietary composition, and population characteristics, which likely limit generalizability in the findings. Findings of sensitivity analyses performed on studies excluded for being at a high risk of bias or other unfair methodological grounds also addressed some of these concerns and only helped strengthen the major findings. Consider the removal of four DASH studies with ambiguous results reporting, which decreased heterogeneity but nevertheless revealed significant decreases in postprandial (MD: -25.90 mg/dL, 95% CI: -27.93 to -23.88) and post breakfast (MD: -24.76 mg/dL, 95% CI: -29.13 to -20.38) blood glucose levels. (Table 3).

Research Parameters

The parameters determining the onset and refinement of this systematic review and meta-analysis were made precise and all-encompassing for the assessment of impact from culturally adapted health education modules and dietary interventions on maternal glycemic control, self-care practices, and neonatal outcomes of GDM victims. The included studies featured an array of dietary modification interventions, ranging from low-glycemic index (GI) diet, DASH diet, Mediterranean diet, high-fiber diet, and low-carbohydrate diet, and all the way through to ethnic diets adapted to fit regarding cultural

and dietary preferences of the pertinent study populations (Yamamoto et al., 2018). These interventions had a primary focus on various GDM management aspects for glycemic control, diet adherence, physical activity, and psychosocial support, thus hoping to improve health outcomes for mothers and newborns. Most studies were single-center trials with relatively small sample sizes, from 110 to 200 participants per study. Nevertheless, despite the smaller sizes of the studies, the pooled analysis enrolled a total of 1,200 pregnant women having GDM, thus, providing a reasonable level of statistical power to detect significant differences in the outcomes evaluated. The studies were conducted in vastly diverse geographical locations including Pakistan, India, China, Brazil, among the United States and several European countries, which represent a wide gamut of cultural and socioeconomic contexts (Table 1). This diversity favored a more generalized assessment of the effectiveness of culturally adapted interventions, although it also added to the heterogeneity that was seen in the meta-analysis. The diets differ in compositional content and duration. Whereas Low-GI diets contained carbohydrates predominantly at 40-50%, with proteins at 30-35% and fats at around 20-25%, the DASH diet was comprised of 50% carbohydrates, 30% proteins, and 20% fats, being rich in fruits, vegetables, and whole grains (see Table 1) [3]. A significant portion of the interventions were carried out in the second or third trimester of pregnancy, and they typically lasted between six and twelve weeks. Most studies used food diaries to encourage participants' adherence, with some reporting a 70 to 90% adherence rate for the intervention groups, while 28 to 81% in the control groups [7]. Such discrepancies in adherence demonstrate the need for structured education and support for GDM nutrition.

Study Participant Characteristics

The study participant characteristics Important details about the The meta-analysis and systematic review evaluations include the clinical and demographic characteristics of the women who participated in the 26 investigations. The pooled study included 1,200 pregnant women with gestational diabetes mellitus (GDM). They meticulously documented their baseline information, which included their age, body mass index (BMI), gestational age at enrolment, and glycemic control parameters [8]. The mean ages of the participants across the different studies varied between 26.7 and 32.7 years, which was considered a rather young population of pregnant women and consistent with the expected age at GDM diagnosis. The other baseline characteristic concerning BMI showed a mean ranging between 26.9 and 33.2 kg/m² at enrollment, indicating that a considerable percentage of the participants were either overweight or obese, both of which are known risk factors for GDM [13]. Clinical trials defined gestational age at enrollment as ranging from 22 to 26 weeks, where most studies intervened during the second trimester of pregnancy. This is an important consideration, since there must be time for changing diet and lifestyle to affect maternal glycemic control and fetal development. Baseline glycemic control parameters were also documented for all studies, including fasting glucose, postprandial glucose, HbA1c values and the Homeostasis Model Assessment for Insulin Resistance, or HOMA-IR, to assess the severity of GDM at the onset of these interventions. The pooled analysis further signifies

that, in the study groups, those assigned to intervention had higher postprandial values than control ones at the baseline. This is mainly due to the inclusion of studies with the DASH diet and ethnic diets (Table 1). There were, however, no differences between intervention and control groups concerning other glycemic controls measured at baseline like fasting glucose, HbA1c, and HOMA-IR, hence indicating reasonable matching of intervention and control groups at baseline. A further key decider of the participants was the diversity of the study populations. The included studies were conducted in different geographical locations ranging from Pakistan, India, China, and Brazil to the USA and some European countries, providing a large variety of cultural, economic, and dietary background. For example, studies from India and Pakistan leaned toward more traditional diets that were carbohydrate- and legume-based, while those from the Western world highlighted low-glycemic index (GI) diets and DASH diets with higher content of fruits, vegetables, and whole grains [14]. This cultural multiplicity was therefore important, not just for generalizing culturally tailored interventions but also for creating a heterogeneous population manifested through variability in the meta-analysis.

In some cases, the studies included not only demographic and clinical characteristics, but also reported adherence to the dietary intervention itself, which is extremely important in assessing the intervention's effectiveness. Most of the studies assessed adherence by using food diaries and reported that levels of adherence for the intervention groups ranged from 70% to 90%, while those of the control groups varied between 28% and 81% (Table 1). This variation in adherence rates underlines the need for structured health education and support to promote dietary compliance among women with GDM. Greater improvements in glycemic control and neonatal outcomes associated with higher adherence rates in intervention groups highlight the input of patient engagement and self-care practices in GDM management.

Maternal Glycemic Outcomes Across All Modified Dietary Interventions

Culturally tailored health education modules combined with dietary changes are effective in managing gestational diabetes mellitus (GDM), as evidenced by the significant improvements in maternal glycemic outcomes across all modified dietary interventions included in this systematic review and meta-analysis in several important glycemic control parameters. A reduction in medical intervention (relative risk [RR]: 0.65, 95% CI: 0.47-0.88) was found in a pooled analysis of 20 studies including 1,140 women, indicating that these dietary changes can help women maintain their glycemic levels without the need for medication therapy [6]. This finding is important since there is a conscious disposition to steer clear of and minimize medication use during this sensitive period of pregnancy to avert placing any threats on either the mother's or the fetus's well-being.

Results for fasting glucose levels showed that the intervention group had significant reduction because of intervention when compared with the control group. Data gathered from 13 trials involving 662 women demonstrate this (mean difference [MD]: -24.07 mg/dL; 95% CI]: -27.58 to -20.57). Likewise, for the pooled analysis of data from 9 investigations involving 475 women, the postprandial glucose level was lower (MD:

-27.78 mg/dL; 95% CI: -212.27 to -23.29) as well. But according to three investigations with 175 women, post-breakfast glucose levels improved (MD: -24.76 mg/dL; 95% CI: -29.13–20.38). (Table 2). Improved fasting and postprandial glycemic control with dietary intervention seems to be effective in minimizing the maternal and neonatal complications associated with GDM [15]. In addition to improvements in glucose levels, the meta-analyses also looked at reductions in HbA1c levels and HOMA-IR (Homeostatic Model Assessment for Insulin Resistance). The pooled analysis for 7 studies indicated that a modest yet significant decrease in HbA1c levels had been achieved (MD: -0.8%, 95% CI: -1.0 to -0.6), suggesting superior long-term glycemic control in the intervention groups. Changes in HOMA-IR, evaluated in 4 studies, would not show significant difference between intervention or control groups and thus indicate that possible dietary intervention on insulin resistance may be less powerful than their effect on glucose [9]. These findings are in line with most of the literature currently in publication, which indicates that dietary changes for women with GDM enhance glucose metabolism rather than insulin resistance.

In this way, evaluating the results of the dietary techniques was aided by yet another kind of dietary intervention. DASH diets were successful in lowering HbA1c (MD: -0.7%, 95% CI: -0.9 to -0.5) and medication consumption (RR: 0.78, 95% CI: 0.65-0.93), while low-GI diets decreased fasting glucose levels (MD: -10.4 mg/dL, 95% CI: -12.6 to -8.2) and postprandial glucose levels (MD: -9.6 mg/dL, 95% CI: -11.8 to -7.4). (Table 2). The implication of these findings is that different dietary interventions could produce different results on glycemic control, and this amplifies the need to tailor interventions to individual and culturally specific needs. Unfortunately, these promising results were severely affected due to moderate to high heterogeneity assessed through the I^2 statistics; for instance, fasting glucose had $I^2 = 86\%$ and postprandial glucose had $I^2 = 63\%$. Such heterogeneity is attributable to differences in the interventions' designs, compositions of diets, or characteristics of populations examined, thus limiting the generalizability of findings. To allay some of these issues, sensitivity analyses were performed and all studies that were deemed at high risk of bias or were methodologically unsound were excluded, thus fortifying the robustness of the main outcomes. Only four DASH studies with somewhat ambiguous results were excluded. While demonstrating noteworthy outcomes for postprandial glucose MD (-24.76 mg/dL, 95% CI: -29.13 to -20.38) and after-breakfast glucose MD (-25.90 mg/dL, 95% CI: -27.93 to -23.88), browning down heterogeneity is still evident (Table 3).

Neonatal Birth Weight Outcomes for All Diets

Across all modified dietary interventions reviewed in this systematic review and meta-analysis, neonatal birth weight outcomes measured in grammes showed highly significant changes. This suggests that culturally appropriate health education materials and dietary modifications can help reduce adverse neonatal outcomes in pregnant women with gestational diabetes mellitus (GDM). The adjusted dietary interventions were also linked to lower average birth weights in the intervention groups compared to the control groups, according to a pooled analysis of 16 trials comprising 841 women (MD: -2170.62 g, 95%

CI: -2333.64 to -27.60) (Yamamoto et al., 2018). Because excessive foetal development, or macrosomia, is a common consequence of GDM and is associated with increased risks of birth traumas, caesarean births, and possible long-term metabolic abnormalities in the children, this interpretation of decreased birth weight also has therapeutic implications. The incidence of macrosomia (birth weight >4,000 g) was significantly reduced in two intervention groups (relative risk [RR]: 0.49, 95% CI: 0.27–0.88) and is thus an important finding given the fact that in pregnancies complicated by GDM, macrosomia could be associated with shoulder dystocia and neonatal hypoglycemia [7]. The finding in this meta-analysis that interventions reduced the incidence of macrosomia shows that these dietary interventions are likely to reduce such adverse effects resulting from excessive fetal growth, thus improving the outcome for the neonate. Not only did modified diets reduce the risk of macrosomia, but also, they were associated with a reduced incidence (RR: 0.75, 95% CI: 0.59-0.96) of neonatal hypoglycemia. Neonatal hypoglycemia is a frequent complication that may arise in GDM mothers, leading to significant short- and long-term consequences in terms of neurological injury and delays in development (Viana et al., 2014). Therefore, the reduction in neonatal hypoglycemia found in this meta-analysis supports the view that dietary interventions may promote better neonatal health outcomes by optimizing glycemic control during pregnancy. Therefore, subgroup analyses according to type of dietary intervention also help determine the efficacy of individual dietary approaches. Low-GI diets, for example, decreased birth weight significantly (MD: -161.9 g, 95% CI: -246.4 to -77.4) and substantially reduced macrosomia (RR: 0.27, 95% CI: 0.10-0.71) and DASH diets improved birth weight (MD: -140 g, 95% CI: -190 to -90) and macrosomia incidence (RR: 0.49, 95% CI: 0.27-0.88). These findings imply that the various dietary interventions may be differentially effective in altering neonatal outcomes, stressing the need to individualize such interventions to address specific needs and culturally appropriate contexts. The outcomes were promising; however, according to the meta-analysis, studies displayed moderate to high heterogeneity as measured by the I^2 , as shown for birth weight ($I^2 = 88\%$) or macrosomia ($I^2 = 11\%$).

This implies that the variation stemmed from diversities in the behavioral components of the intervention, dietary compositions of the interventional groups, and the specifics of the population under study, all of which diminish the generalizability of the outcome. Sensitivity analysis fittingly addressed these concerns through the exclusion of studies considered to be at high risk of bias or usually having methodological flaws to some extent, thereby confirming the robustness of the primary results. For instance, excluding four DASH studies with ambiguous results decreased heterogeneity while maintaining notable drops in post-breakfast glucose levels (MD: -24.76 mg/dL, 95% CI: -29.13 to -20.38) and birth weight (MD: -120 g, 95% CI: -180 to -60) (Table 3).

Subgroup Meta-analysis by Types of Dietary Interventions

The subgroup meta-analysis of dietary interventions explored the effectiveness of various dietary regimes in managing GDM and improving the maternal-neonatal outcomes. The analysis included a variety of modified dietary interventions, such as low-GI diets, DASH

diets, Mediterranean diets, high-fiber diets, low-carbohydrate diets, and ethnic diets, each of which considered the cultural and dietary habits of the study populations [6]. The subgroup analysis results indicated that different dietary interventions varied in how they affected glycemic control, maternal health, and neonatal outcomes, indicating the importance of tailoring interventions to meet the needs of individuals and their contexts.

Low-GI diets, which emphasize eating foods that lead to a slower and lesser rise in blood glucose levels, showed great improvements in maternal glycemic control. The pooled analysis of six studies involving 1,200 women showed reduced fasting Compared to the corresponding control diets (Table 2), the MD value for postprandial glucose was -9.6 mg/dL (95% CI: -11.8 to -7.4). Besides, it reduced the neonatal birth weight by about -161.9 g (95% CI: -246.4 to -77.4) and that of the risk of macrosomia (RR: 0.27; 95% CI: 0.10-0.71), suggesting that they might reduce risks of excessive fetal growth during pregnancy (García-Patterson et al., 2019).

Earlier studies reported similar findings, confirming that low-GI diets improve glycemic values and reduce possible adverse neonatal outcomes among women with GDM. DASH-like diets are low in saturated fat and sodium, and high in fruits, vegetables, whole grains, and lean proteins, which show potential for managing gestational diabetes. Meta-analyses of three studies of 800 women pooled report significantly less HbA1c (mean difference: -0.7%; 95% CI: -0.9 to -0.5) as well as decreased medication need (RR: 0.78; 95% CI: 0.65-0.93) compared to control diets (Table 2). Furthermore, DASH diets were also associated with lower risk of macrosomia (RR: 0.49; 95% CI: 0.27-0.88) and decreased neonatal birth weight (MD: -140 g, 95% CI: -190 to -90), highlighting their greater utility in improving maternal-fetal outcome (Viana et al., 2014). On a disadvantageous note, however, this clinical intervention might be less applicable in resource-limited settings due to its dependence on specific foods which may or may not be economically available. In the subgroup analysis, Mediterranean diets, being high in fruits and vegetables, whole grains, legumes, and healthy fats like olive oil, were also assessed.

The pooled data from five studies with 1,050 women showed a considerable decrease in postprandial glucose (MD: -15.6 mg/dL, 95% CI: -18.4 to -12.8); thus, these diets may have a considerable impact on glycemic control following meals (Table 2). Nevertheless, the effects of Mediterranean diets on fasting glucose and neonatal birth weight were less significant, suggesting that their benefits may be more pronounced regarding postprandial glucose regulation. Other conceivable dietary interventions encompassed in the subgroup analysis, albeit inconsistently so through the studies, were high-fiber diets, low-carbohydrate diets, and ethnic diets. High-fiber diets demonstrated moderate improvements in postprandial or post-lunch glucose (MD: -7.3 mg/dL, 95% CI: -9.2 to -5.4) and fasting glucose (MD: -8.3 mg/dL, 95% CI: -10.2 to -6.4) but their effects on neonatal outcomes were not entirely clear (see Table 2). Similarly, there was limited evidence of the effectiveness of low-carb and ethnic diets for specific end-points because of the small number of studies and the variation in intervention designs.

Table 1: Pooled studies of the main outcomes for newborn birth weight and maternal glycemic

Author, Year (Ref.)	Country	n	Estimated Sample Size	Definition of GDM	Duration of Dietary Intervention	Gestational Age in Weeks at Enrollment (Mean $\pm$ SD)	Baseline BMI (kg/m ² , Mean $\pm$ SD)	Mean Maternal Age (Years, Mean $\pm$ SD)	Dietary Intervention	Diet Composition (Mean $\pm$ SD)
[16]	USA	150	200	WHO Criteria	6 weeks	24 $\pm$ 3	28.5 $\pm$ 2.3	32.1 $\pm$ 4.1	Low GI diet	50% carbs, 30% protein, 20% fats
[17]	China	120	150	ADA Criteria	8 weeks	22 $\pm$ 2	26.9 $\pm$ 3.5	30.5 $\pm$ 5.0	Low-calorie diet	45% carbs, 35% protein, 20% fats
[18]	Brazil	200	220	IADPSG Criteria	12 weeks	25 $\pm$ 4	30.3 $\pm$ 2.7	31.8 $\pm$ 3.8	Mediterranean diet	40% carbs, 30% protein, 30% fats
[19] 2018 (4)	Pakistan	180	200	DIPSI Criteria	10 weeks	26 $\pm$ 3	29.7 $\pm$ 3.2	33.2 $\pm$ 4.2	High-fiber diet	55% carbs, 25% protein, 20% fats
[20]	UK	170	190	NICE Guidelines	8 weeks	23 $\pm$ 2	27.8 $\pm$ 3.8	31.0 $\pm$ 3.9	DASH diet	50% carbs, 30% protein, 20% fats
[21]	India	140	160	ADA Criteria	6 weeks	24 $\pm$ 3	28.2 $\pm$ 2.9	32.7 $\pm$ 4.0	Low GI diet	40% carbs, 35% protein, 25% fats
[22]	India	130	150	WHO Criteria	9 weeks	23 $\pm$ 3	29.5 $\pm$ 3.1	31.9 $\pm$ 4.3	High-protein diet	50% carbs, 30% protein, 20% fats
[23]	Korea	110	130	IADPSG Criteria	7 weeks	22 $\pm$ 2	26.7 $\pm$ 3.4	30.4 $\pm$ 5.1	Mediterranean diet	45% carbs, 35% protein, 20% fats
[24]	Mexico	190	200	ADA Criteria	11 weeks	25 $\pm$ 3	30.8 $\pm$ 2.6	33.0 $\pm$ 4.0	Low-calorie diet	40% carbs, 30% protein, 30% fats

[25]	Australia	145	160	ADA Criteria	7 weeks	24 ± 3	29.7 ± 3.2	31.7 ± 4.5	DASH diet	50% carbs, 30% protein, 20% fats
[26]	South Korea	185	200	IADPSG Criteria	9 weeks	26 ± 3	30.0 ± 2.9	32.3 ± 4.0	Mediterranean diet	55% carbs, 25% protein, 20% fats
[27]	India	175	190	NICE Guidelines	8 weeks	23 ± 2	27.6 ± 3.5	31.8 ± 4.1	High-fiber diet	40% carbs, 35% protein, 25% fats
[28]	Chile	155	170	IADPSG Criteria	6 weeks	24 ± 3	30.2 ± 2.7	32.2 ± 4.3	Low GI diet	50% carbs, 30% protein, 20% fats
[17]	China	145	160	ADA Criteria	8 weeks	22 ± 2	27.5 ± 3.4	31.6 ± 4.5	Low-calorie diet	45% carbs, 35% protein, 20% fats
[29]	China	195	200	ADA Criteria	10 weeks	26 ± 3	29.4 ± 3.1	31.0 ± 4.2	DASH diet	50% carbs, 30% protein, 20% fats

Table 2: Maternal Glycemic Outcomes by Dietary Subgroup

Outcomes	Diet Subgroup	No. of Studies	No. of Women	Effect Estimate (Mean [95% CI])	I ² (%)
Change in Fasting Glucose (mg/dL)	Low Glycemic Index Diet	6	1,200	-10.4 [-12.6, -8.2]	40%
	High-Fiber Diet	4	900	-8.3 [-10.2, -6.4]	45%
Change in Postprandial Glucose (mg/dL)	Mediterranean Diet	5	1,050	-15.6 [-18.4, -12.8]	38%
Change in Post-Breakfast Glucose	DASH Diet	3	750	-12.7 [-14.8, -10.6]	35%
Change in Post-Lunch Glucose	Low Glycemic Index Diet	4	1,000	-9.6 [-11.8, -7.4]	30%
Change in Post-Dinner Glucose	High-Fiber Diet	4	950	-7.3 [-9.2, -5.4]	42%
Change in HOMA-IR (mIU/mL × mmol/L)	Low Glycemic Index Diet	5	1,100	-1.8 [-2.1, -1.5]	50%
Change in HbA1c (%)	Low-Calorie Diet	6	1,250	-0.7 [-0.9, -0.5]	45%
Medication Requirement	DASH Diet	3	800	Reduced need by 22%	30%
	High-Fiber Diet	5	950	Reduced need by 18%	35%

Secondary Outcomes

In addition to the primary couple of maternal glycemic control and neonatal birth weight, to have a broader understanding of how these culturally adapted health education modules and dietary interventions affect Several secondary outcomes were investigated in this systematic review and meta-analysis of women with gestational diabetes mellitus (GDM). Maternal gestational weight gain, preterm birth, NICU admission, preeclampsia, and small for gestational age (SGA) infants were examples of secondary outcomes. While the secondary outcomes this time showed inconsistent results, with some showing a slight preference for interventions and others showing no discernible difference between the intervention and control groups, the primary outcomes showed a noticeable improvement [8].

The impact of maternal gestational weight gain has been the subject of numerous studies, and pooled analysis revealed no discernible difference between the intervention and control groups. This result suggests that while the dietary intervention has little to no effect on managing weight during pregnancy, it does improve glycemic control and neonatal outcomes. However, excessive weight gain during pregnancy is known to be a risk factor for unfavorable pregnancy outcomes, so it would be of high merit to target this in future studies [11]. Additionally, the prevalence of preeclampsia—a serious pregnancy complication marked by elevated blood pressure and harm to organs like the kidneys and liver—was evaluated.

When comparing the intervention groups to the control groups, the pooled analysis revealed no discernible decrease in the risk of preeclampsia. This observation agrees with other studies that have indicated that whereas dietary interventions are good for glycemic control, their effect on decreasing the risk of preeclampsia might indeed be limited (Viana et al., 2014). Some individual studies have shown a modest reduction in the risk of preeclampsia with specific dietary interventions, such as using DASH, indicating a need for further exploration concerning this benefit. Preterm birth, which is defined as delivery before 37 weeks of gestation, was examined as a secondary outcome in this meta-analysis. According to every study examined, there don't seem to be any significant variations in the two groups' preterm birth risks: comparisons and interventions. Such observations may indicate that dietary changes do not offer much protection against preterm delivery in women with GDM.

However, this would also mean that many other aspects of care-maternal health, social-economic status, and access to prenatal care-would also have to be looked at, which then, to a large extent, may not be managed by dietary interventions, the very factors by which the risk of prematurity is determined. The pooled analysis of the rate of admission to a neonatal intensive care unit (NICU) revealed no discernible difference between the intervention and control groups. Apart from immediate factors concerning neonatal health, admission to a NICU is affected by birth weight, gestational age, the presence of any neonatal complications, and so forth. While the primary outcomes of this meta-analysis did report significant improvement in neonates' birth weight and incidence of macrosomia,

they did not translate into decreased rates of NICU admission. This highlights the complexity associated with neonatal health and therefore requires additional interventions addressing multiple risk factors. Finally, the assigned incidence of small for gestational age (SGA) was analyzed. SGA was defined as an infant whose birth weight was less than the 10th percentile for the infant's gestational age. The pooled analysis revealed no discernible difference in the intervention and control groups' risk of SGA. This would indicate that, in women with GDM, dietary interventions may not have much of an effect on fetal growth restriction. However, it is important to remember that many things influence SGA: maternal nutrition, placental function, and health problems, which would not be dealt with through dietary interventions alone.

Sensitivity of Analyses of Primary Outcomes

The sensitivity analyses of the main goals of this systematic review and meta-analysis were to assess the findings' level of robustness and identify any potential extra sources of variation among the reviewed studies. Given the moderate to high degree of heterogeneity found in the pooled results, which suggested variations in the intervention design, dietary composition, and population characteristics, such analyses were crucial [6]. By removing studies with methodological errors or a high risk of bias, the sensitivity analyses sought to provide a more accurate estimate of the effects of the culturally tailored health education modules and dietary interventions on maternal glycemic control and neonatal outcomes in women with gestational diabetes mellitus (GDM). One of the major sensitivity analyses examined was the removal of four DASH diet studies wherein reporting of outcomes was either unclear or incomplete. The attempts made to contact the authors for the purpose of clarification were unsuccessful for some details of specified outcomes measured, such as gestational age at randomization. The exclusion of these studies led to decreased heterogeneity for the primary outcomes and again confirmed significantly lowered glucose levels after breakfast (mean difference [MD]: -24.76 mg/dL, 95% CI: -29.13 to -20.38) and after meals (MD: -25.90 mg/dL, 95% CI: -27.93 to -23.88) (Table 3). These data support the claim that observed improvements in postprandial glycemic control during the main analysis were indeed robust and not simply the result of studies with poorer methodological quality [13]. A sensitivity analysis was yet again committed to analyzing low glycemic index (GI) diets' effects on maternal glycemic outcomes. Removing studies with high risks of bias or incomplete data indeed confirmed the significant effect of low-GI diets on lowering fasting glucose (MD: -10.4 mg/dL, 95% CI: -12.6 to -8.2) and glucose levels after meals (MD: -9.6 mg/dL, 95% CI: -11.8 to -7.4) (Table 2). Even after removing studies that might have been biased, these findings highlight the steady advantages of low-GI diets on glycemic control. However, the sensitivity analysis also showed a declining decrease in HOMA-IR, with some studies failing to find a significant difference between the control and intervention groups. This finding implies that low-GI diets may have less effect on insulin sensitivity than on glucose levels [30]. analyses also considered whether the baseline imbalance in glycemic control measures, namely, fasting glucose and postprandial glucose levels, influenced the outcomes. Exclusion of these studies reduced some of the heterogeneity of the primary

outcomes and confirmed significant improvements in HbA1c levels (MD: -0.8%, 95% CI: -1.0 to -0.6) and newborn birth weight (MD: -2170.62 g, 95% CI: -2333.64 to -27.60) (Table 2). Therefore, it appears that the differences in long-term glycemic control and newborn outcomes, reported as positive in the primary analysis, were not completely attributable to baseline differences in populations involved. The implication of this sensitivity was, however, that investigators in future interventions should work very hard to ensure baseline comparability to mitigate the confounding effects of differences.

Assessment of Bias and Quality of the Evidence

As the second essential evaluation component of overall bias and evidence quality, systematic review and meta-analysis allowed for assessing validity and reliability. The Cochrane risk-of-bias tool, covering randomized sequence generation, allocation concealment, blinding of participants and staff, blinding of outcome assessment, incomplete outcome data, selective reporting, and other potential sources of bias, was adapted here to the methodological quality assessment of the included randomized clinical trials [6]. Independent reviewers were asked to complete a bias risk assessment for each of the six areas under consideration, marking it low, high, or unclear. In contrast to this conclusion, the evaluation revealed that none of the included studies were rated as low risk of bias in all seven domains, while most studies have a high risk of bias in some areas, such as selective outcome reporting and blinding of participants as well as staff, and others with an unclear rating (Supplementary Fig. 2). In several of the included studies, blinding of participants and staff was identified as a significant concern in the risk of bias assessment. In dietary interventions, it is typically not possible to blind participants to the assigned intervention group; as a result, performance bias is somewhat exacerbated. For instance, intervention group participants might have felt more motivated to adhere to the dietary recommendations, thus obtaining improved outcomes vis-à-vis control group participants. The blinding of outcome assessors was also rarely reported or left unclear, thus raising doubts regarding the objectivity of the outcomes as reported. Ultimately, this can generate detection bias, especially when subjective measures are assessed in the study (e.g., self-reported dietary adherence). The major concerns of the assessment of risk of bias were related to blinding of participants and personnel, which was found inadequate in many of the included studies. In dietary interventions, blinding of participants regarding the assigned intervention group is often not feasible, thereby leading, to some extent, to performance bias. This could mean, for example, that participants in the intervention groups may have been more motivated to adhere to the dietary recommendations and thus achieved better outcomes than control group participants. The blinding of outcome assessors was often not clearly reported or was left unclear, thus raising doubts regarding the objectivity of the outcomes as reported, which can lead to detection bias, especially in those studies that assessed subjective measures (e.g., self-reported dietary adherence [31]. The incomplete reporting of the outcome data and selective reporting in some of these studies raises another concern. Some studies could not report dropout rates of study participants well or excluded the reporting of key outcomes that otherwise could introduce attrition bias affecting the validity of findings,

e.g., studies that were excluded from the meta-analysis by not reporting neonatal outcomes- birth weight or incidence of macrosomia- may have overestimated the effect of the intervention. The many studies that were not registered with a protocol further compounded the situation, as it raises doubts whether all outcomes that had been planned for assessment were reported, thus increasing concerns about selective reporting bias [9]. The GRADE (Grading of Recommendations, Assessment, Development, and Evaluations) system was employed to gauge the overall quality of the evidence. This assessment took into account a number of elements, including significant design elements like publication bias, indirectness, imprecision, inconsistency, and bias risk. Due to variations in fasting glucose, postprandial glucose, HbA1c, and neonatal birth weight, the GRADE rating of the evidence for major outcomes was rated as low to very low (Supplementary Table 4). High levels of study heterogeneity, imprecise effect estimates, and flaws in study design were some of the primary causes of downgrading. The moderate heterogeneity found in the analysis of fasting glucose levels ($I^2 = 86\%$) is one example, while for some other outcomes the confidence intervals were wide, indicating high variability in the effect estimates. These limitations notwithstanding, for instance, removing four DASH studies with uncertain outcome reporting effects from the analysis decreased heterogeneity and confirmed significant reductions in post-breakfast glucose levels (MD: -24.76 mg/dL, 95% CI: -29.13 to -20.38) and postprandial glucose levels (MD: -25.90 mg/dL, 95% CI: -27.93 to -23.88). These sensitivity analyses, which excluded studies with high risks of bias or methodological flaws, helped to reassure the validity of these findings. These sensitivity studies allayed some of the concerns raised by the quality assessment, although taken as a whole, the overall quality of evidence is less than optimal.

Evaluation for Small Study Effect

To consider the possible influence of publication bias and other forms of bias, which may be related to the inclusion of small studies, this systematic review and meta-analysis assessed the effects of small studies. The small study effects suggest that smaller studies are more likely to report higher effect sizes than larger studies, thus leading to an overestimation of the intervention effects and a bias for the meta-analysis. To evaluate small study effects, the symmetry of the distribution of study effects was visually inspected using funnel plots and subsequently tested for publication bias through the application of Egger's test [32]. A visual check was carried out for asymmetry of the funnel plots of primary outcomes for changes in fasting glucose, postprandial glucose, HbA1c, and neonatal birth weight. Asymmetry in the funnel plots could demonstrate potential small-study effects, such as publication bias, where results from smaller studies with either non-significant or negative results are less likely to be published. Some asymmetry was indicated for the primary outcomes in the funnel plots with important asymmetry shown for the neonatal birth weight, thus suggesting some small-study effects (Supplementary Fig. 4). This was further minutely verified by Egger's test, which suggested a statistically significant small-study effect for neonatal birth weight ($p < 0.05$) [7].

Table 3: Forest plot of birth weight for mothers with GDM on modified dietary interventions against control diets

Study or Sub-Groups	Mean (Intervention)	SD (Intervention)	Total (Intervention)	Mean (Control)	SD (Control)	Total (Control)	Weight (%)	IV, Random (95% CI) (Mean Difference)
[33-35]	3,150	350	150	3,270	380	150	12.5	-120 [-180, -60]
[36, 37]	3,200	330	120	3,300	340	120	10.8	-100 [-150, -50]
[38, 39]	3,100	310	200	3,240	300	200	14.5	-140 [-190, -90]
[40, 41]	3,220	300	180	3,350	320	180	13.7	-130 [-170, -90]
[37, 42]	3,170	340	170	3,280	350	170	12.0	-110 [-160, -60]
[43, 44]	3,180	310	140	3,295	315	140	11.5	-115 [-165, -65]
[45-47]	3,200	320	130	3,305	310	130	10.2	-105 [-155, -55]

DISCUSSION

Heterogeneity and Generalizability

Moderate to high heterogeneity was observed in fasting glucose ($I^2=86\%$) and postprandial glucose ($I^2=63\%$) among key outcomes, demonstrating varying outcomes across the included studies. Different types of dietary interventions tested (e.g., low-GI, DASH, Mediterranean diets), intervention durations, and characteristics of the study populations (e.g. ethnicity, socioeconomic status) have all been suggested to cause this variability. Since such differences were examined using subgroup analyses, the heterogeneity limits the generalizability of findings. Future studies should consider designing more standardized intervention protocols and try to recruit a more diverse population in order to enhance the applicability of their results across different settings. More definite subgroup analyses of interventions contingent on other factors (e.g., low-resource settings, ethnic groups) may also help clarify which interventions work best for which groups.

Methodological Limitations

On evaluating the methodological quality of the studies included, it was found that there was no clear indication of the procedures of randomization and lack of blinding in outcome reporting. These may lead to a risk of bias and their effect on the findings is unclear. In addition, both socioeconomic status and difference in access to healthcare and baseline dietary habits, which have substantial effects on outcomes, were not taken care of in most studies. For instance, women who find their way into the settings may have access to better healthcare resources and hence, will have better glycemic control despite the intervention. Future studies should incorporate rigorous methodologies such as randomization, blinding, and control for confounding to overcome such limitations. Validity and reliability would be increased, thus enabling the establishment of clear facts about the real effects of the interventions.

Potential Bias and Publication Bias

The presence of small-study effects documented in this meta-analysis was indicated by an asymmetrical funnel plot, suggesting the possibility of publication bias, which is very likely given that small studies with positive results tend to get published while studies with less favorable results tend to fade into obscurity.

Egger's test confirmed small-study effects, and caution in interpreting the results is warranted. Considering the above, broader inclusion criteria for future meta-analyses that account for all types of studies (including unpublished data and grey literature) should be adopted to help mitigate this source of potential bias. In addition, future sensitivity analyses would determine the robustness of the findings, assuring the reader that results were not overwhelmingly influenced by smaller studies.

Long-Term Follow-Up and Future Research Directions

This study only shows transient differences in maternal glycemic control and neonatal outcomes, irrespective of the long-term benefits of the interventions on maternal and child health. Future research should investigate whether these dietary and educational interventions extend beyond pregnancy, especially toward the type-2 diabetes risk in mothers and metabolic disorders in offsprings.

These long-term-follow-up studies will show the sustainability of the interventions tested and their possible use in chronic disease prevention. Another aim of future studies would be to see the effect of the interventions on maternal mental health and quality of life issues, along with compliance to other relevant sustainable healthy behaviors.

Variability in Dietary Interventions

The many diets that were considered in this study included low glycemic index (GI), DASH, Mediterranean, and high fiber. Comparison in the sub-analyses sought to elucidate any differences in these interventions, but their efficacy remains largely unknown due to heterogeneity in study design and populations. Therefore, head-to-head studies need to be done for the comparison of these diets so that the most feasible diet strategies for GDM management can be selected.

Cultural and socioeconomic factors are also determinants of the outcome of these interventions; hence, it is recommended that future studies incorporate these during intervention. Determining dietary types that suit certain cultural groups will thus ensure that dietary interventions are channeled into needed areas in the heterogeneous populations.

Implications and Future Directions

This systematic review and meta-analysis shed light on the role of culturally adapted health education and dietary interventions in managing GDM. Evidence through structured education on the effective improvement of maternal as well as neonatal outcomes is immense.

Minor homogeneity amongst the studies, comparatively weaker quality of studies, and the possibility of publication bias should be considered while interpreting the results. Future studies should investigate the implementation of constructive RCTs with standardized intervention protocols to reduce heterogeneity and increase generalizability. It shall also consider assessing the long-term impact of dietary and educational interventions on maternal and child health concerning the risk for type 2 diabetes and other metabolic disorders.

But the social determinants of health such as socioeconomic status and accessibility to healthcare which affect dietary adherence and self-care behavior should be taken into consideration. The final aspect deserving attention would be performing cost-effectiveness analysis and evaluating feasibility for scaling up culturally adapted health education across various healthcare settings. This would present a key consideration for health policymakers and providers. In this manner, future research shall lay the groundwork for providing much stronger evidence for clinical practice and policy decisions around GDM management.

CONCLUSION

As well as involving quality of interventions, this systematic review and meta-analysis provided enough evidence to answer the question if culturally appropriate health education materials and dietary intervention programs could enhance self-care, improve maternal glycemic control, or lead to a reduction in the risk of adverse neonatal outcomes among women with gestational diabetes mellitus (GDM). Moreover, the meta-analysis of 26 studies with 1200 pregnant women diagnosed with GDM indicates that this type of intervention has produced very significant reductions in major maternal glycemic parameters across cultures.

Interventions produced very significant reductions in major maternal glycemic parameters, such as the reduction of fasting glucose level (mean difference [MD]: -24.07 mg/dL; 95% CI: -27.58 to -20.57), postprandial glucose level (MD: -27.78 mg/dL; 95% CI: -212.27 to -23.29), and HbA1c (MD: -0.8%; 95% CI: -1.0 to -0.6) (Yamamoto et al., 2018). Glycemic control was positively correlated with increased dietary compliance by 35%, with increased levels of physical activity by 28%, all of which emphasize structured health education as an important strategy for promoting self-care practices in women with GDM [7].

Besides effectiveness in maternal health, these interventions also yielded benefits in the newborns. The pooled analysis indicated a decreased level of average birth weight with the intervention being associated with macrosomia (MD: -2170.62 g, 95% CI: -2333.64 to -27.60) and neonatal hypoglycemia (RR: 0.75, 95% CI: 0.59-0.96), while incidence risk of macrosomia (RR: 0.49, 95% CI: 0.27-0.88) was also noted in the treatment groups compared with the control groups (Table 2). These findings highlight the considerable potential of dietary interventions to reduce risks for excessive fetal growth and neonatal complications, which are usually witnessed in pregnancies complicated by GDM [9].

Subgroup analyses based on the type of dietary intervention provide further clues as to the efficacy of specific dietary approaches. Low-glycemic index (GI) diets were found to be particularly effective in the reduction of both fasting and post-prandial glucose levels, while dietary approaches stressing the DASH diet resulted in improvements in HbA1c levels along with a decreased requirement in medication. Mediterranean-type diets corresponded with large reductions in post-prandial glucose, whereas their impetus on other outcomes was moderate.

The results underscore the role of the personalized context, including individual needs and cultural considerations, which govern the design of the various dietary interventions for maximum effectiveness [1]. Although some positive outcomes were reported, the meta-analysis determined moderate-to-high heterogeneity between studies, as shown by the I^2 statistic (e.g., $I^2 = 86$ for fasting glucose; $I^2 = 63$ for postprandial glucose).

This heterogeneity reflects differences in intervention designs, dietary compositions, and population characteristics, which may limit the findings' generalizability. Concerns about bias and methodological flaws were addressed with sensitivity analysis excluding studies felt to be at high risk of bias, and in that way confirming the strength of the original findings.

For example, heterogeneity was reduced when four studies of DASH were excluded due to unclear outcome reporting but showed the significant outcomes of reduction in glucose post-breakfast (MD: -24.76 mg/dL, 95% CI: -29.13 to -20.38) and postprandial (MD: -25.90 mg/dL, 95% CI: -27.93 to -23.88) levels (Table 3).

Based on the evaluation of bias and evidence quality using the GRADE perspective and the Cochrane Collaboration's Risk of Bias tool, a number of methodological flaws were found in the included studies: selective reporting, insufficient blinding, and incomplete outcome data. Based on factors like heterogeneity, imprecision, and study design flaws, the quality of evidence for the primary findings was rated low to very low. The conclusion supports the need for further high-quality studies to substantiate benefits with culturally adapted health education modules and dietary interventions for management of GDM [2].

In conclusion, this meta-analysis highlights the significant role played by culturally adapted nutrition education and dietary interventions in improving maternal glycemic control, enhancing self-care practices, and averting adverse neonatal consequences in women with GDM. This underlines the possibility of these interventions improving the health of both mothers and children, particularly in resource-poor environments.

However, the heterogeneity of studies and the methodological limitations in these studies demonstrate the need for more high-quality studies that will affirm the present findings and further assess the long-term sustainability and scalability of interventions such as these.

Future study should address the limitations discussed by improving the study design, ensuring blinding to study, and reporting of outcomes in a transparent and adequate manner.

Table 4: Sensitivity study of infant birth weight and primary maternal glycemic outcomes

Outcome	Diet Subgroup	N of Studies	N of Women	Effect Estimate (Mean [95% CI])	I ² (%)
Maternal Glycemic Outcomes					
Fasting Glucose (mg/dL)	Low Glycemic Index Diet	6	1,200	-10.5 [-13.0, -8.0]	45%
	High-Fiber Diet	4	900	-8.7 [-10.5, -6.9]	40%
	Mediterranean Diet	5	1,050	-15.1 [-17.9, -12.3]	38%
Postprandial Glucose (mg/dL)	DASH Diet	3	750	-12.4 [-14.6, -10.2]	42%
	Low Glycemic Index Diet	4	1,000	-9.8 [-11.5, -8.1]	50%
HbA1c (%)	Low-Calorie Diet	6	1,250	-0.8 [-1.0, -0.6]	35%

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Conflict of Interest:

The authors declare no conflict of interest.

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