

Effect of Nutrition Education Intervention Based on Health Belief Model on Dietary Diversity Practices of Pregnant Women in Rural Western Ethiopia: A Cluster Randomized Controlled Trial, 2026

Koang Nyak Bol^{1*}, Sebit Mustafa Sebit¹, Surender Reddy Pulluri²

¹Department of Public Health, School of Public Health and Social Work, Texila American University, Guyana, South America

²Department of Public Health, Gambella University, Gambella Region, Ethiopia

***Correspondence to be addressed:** E-mail - koangnbl@gmail.com

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Abstract *Inadequate dietary diversity during pregnancy is a major public health concern in Ethiopia, contributing to maternal undernutrition and adverse pregnancy outcomes. Theory-based nutrition education interventions have shown promise but have not been rigorously evaluated in remote, low-resource settings using cluster-randomized designs. This study aimed to assess the effect of a nutrition education intervention based on the Health Belief Model (HBM) on dietary diversity practices of pregnant women in rural western Ethiopia. A community-based pretest-posttest cluster-randomized controlled trial was conducted among 328 pregnant women (164 per arm) selected from 22 kebeles in Nuer Zone, Gambella Region, from March to June 2026. A 24-hour dietary recall was used to assess dietary diversity. Generalized Estimating Equations (GEE) fitted with a negative binomial distribution and Difference-in-Differences (DiD) were used to assess the intervention effect. At baseline, both groups exhibited comparable proportions of inadequate dietary diversity (intervention 75.3%, control 73.0%). At endline, the proportion of pregnant women with adequate dietary diversity rose from 24.7% to 73.5% in the intervention group but declined from 27.0% to 6.9% in the control group. In the adjusted GEE model, the intervention led to 42.5% greater relative increase in Dietary Diversity Score (IRR = 1.425, 95% CI: 1.322–1.535, $p < 0.001$), indicating robust improvement in dietary diversity and protection against seasonal dietary decline. An HBM-based nutrition education intervention significantly improved dietary diversity among pregnant women in rural western Ethiopia. Integrating behaviorally informed nutrition education into routine antenatal care services is recommended to improve dietary diversity of pregnant women in resource-limited settings.*

Keywords *Cluster-randomized Controlled Trial, Dietary Diversity, Education Intervention, Health Belief Model, Maternal Nutrition, Pregnant Women, Rural Ethiopia.*

Introduction

Dietary diversity refers to the variety or number of different food groups consumed by an individual over a given time [1]. Pregnant women should consume a variety of foods rich in bioavailable energy, protein, vitamins, and minerals to support appropriate maternal weight gain and promote a healthy intrauterine environment for fetal growth and development [1]. According to studies, the overall energy requirement increases by 13% during pregnancy [2]. In low-income countries in Africa and Asia, monotonous cereal-based foods (starchy staples), which are poor sources of micronutrients, are the main cause of the highest burden of maternal undernutrition compared to other regions [3]. Poor maternal nutrition during pregnancy leads to dreadful health consequences for both the mother and the fetus [4]. It causes adverse birth outcomes such as intrauterine growth restriction, low birth weight, and preterm birth [5]. These consequences cause an estimated 800,000 newborn deaths each year globally [4]. Moreover, it is associated with child stunting and wasting [6]. Sub-Saharan Africa and South Asia are severely affected by maternal undernutrition due to chronic micronutrient deficiencies [7].

Factors influencing dietary diversity practices of pregnant women encompass multifaceted sociocultural, economic, and environmental factors, leading to disproportionate variations in the burden of undernutrition across geographical regions, countries, and societies [8]. Studies indicated that a substantial number of pregnant women worldwide have limited knowledge of what constitutes a “diversified diet”, comprising nutrient-dense animal-source foods, vegetables, and fruits for optimal nutrition [9]. Ethiopia is a highly diverse country, comprising more than 80 ethnicities with different food cultures and traditions. It has diverse climates and landscapes with varying rainfall, creating large differences in crop

production and agricultural practices that affect food security and dietary diversity. Ethiopian government has striven to promote maternal nutrition over the past two decades. In its healthcare delivery policy, it integrated nutrition counselling into routine antenatal care services to improve nutrition knowledge of mothers [5]. It developed Food-Based Dietary Guidelines (FBDG) as a game-changing solution to transform the country’s food system, provide evidence-based recommendations for healthy, diverse, and sustainable diets, and improve nutrition literacy [10]. Besides, Ethiopia introduced the Women's Development Army (WDA) and the Health Development Army (HDA) initiatives to enhance community empowerment and engagement in promoting maternal and child healthcare practices [11]. Despite these efforts, inadequate dietary diversity among pregnant women in Ethiopia remains high, ranging from 39.3% to 66.1% [9]. In 2015, only one-fifth (20.3%) of reproductive-age women had minimum (adequate) dietary diversity [12]. In line with this, Ethiopia has a high prevalence of undernutrition among pregnant women, surpassing the average (20%) in Africa [13, 14]. The prevalence of inadequate dietary diversity among Ethiopian women is high in rural settings [15]. According to a case study review of program implementation experience to improve maternal nutrition in Ethiopia, education and counselling provided through routine health systems were ineffective in changing nutrition behaviours [16].

Ideally, behavioural interventions are developed and tested using theory in the settings where they occur to understand the causal determinants of behaviours and the pathways of change [17]. Theory provides a framework for testing hypotheses, identifies constructs that influence behaviour, and suggests techniques to incorporate into behavioural interventions [18]. The Health Belief Model is a widely used theory in health promotion and disease prevention programs

[19]. It is a psychological model that predicts health behaviours by focusing on individuals' perceptions and beliefs [9]. The Health Belief Model is organized into six constructs: perceived susceptibility to illness (disease-related condition), perceived severity of illness, perceived benefits of adopting a healthy behaviour, perceived barriers to behaviour, self-efficacy, and cues to action [19]. According to this model, health behaviour is determined by an individual's

perception of the threat of illness and belief in the effectiveness of a course of action in preventing the illness at affordable costs [19]. Behavioral researchers found that the Health Belief Model effectively improved complex health and nutrition behaviors across populations and cultures [20]. In a study of pregnant women in Iran, a Health Belief Model-based education intervention significantly improved nutrition knowledge from 3% to 31% [21] (Figure 1).

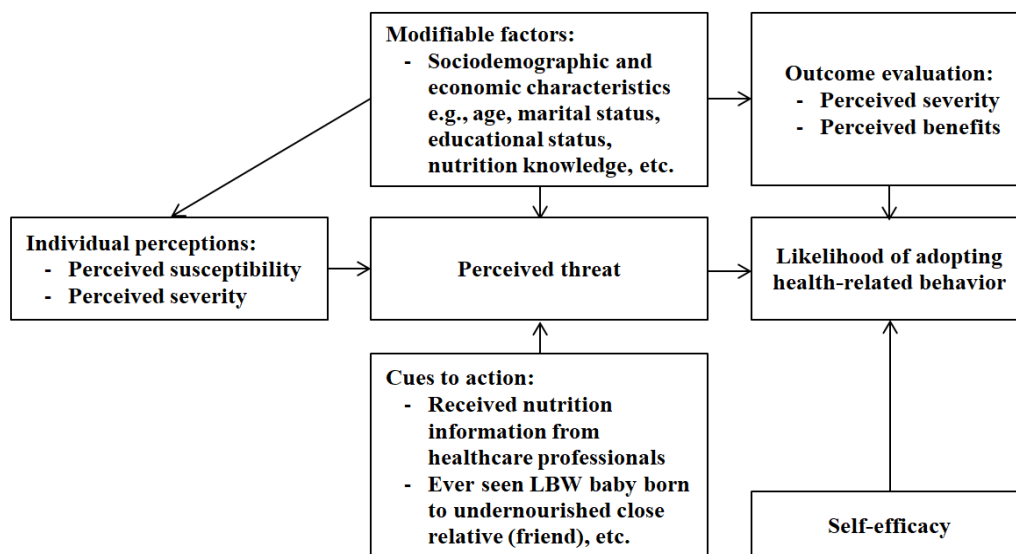


Figure 1. Theoretical Framework for Promoting Dietary Diversity among Pregnant Women using the Health Belief Model [9, 19, 20].

While numerous studies have explored nutrition education interventions in Ethiopia [3], few have employed cluster-randomized designs to evaluate behavioral factors influencing dietary diversity practices among pregnant women in rural pastoralist settings, with limited theory-based evidence in the unique, pastoralist western lowlands of Ethiopia, where the food culture and livelihood patterns differ markedly from agricultural highland communities. Understanding the pathways shaping women's dietary practices in these settings is crucial for designing effective, contextually appropriate education interventions. This study therefore aimed to assess the effect of a nutrition education intervention, grounded in the Health Belief Model, on the dietary diversity practices

of pregnant women in rural western Ethiopia. The findings will inform the development of socially and culturally appropriate nutrition education strategies to improve dietary diversity among pregnant women in similar settings.

Methods and Materials

Study Design and Setting

This community-based, two-arm, parallel-group cluster-randomized controlled trial with baseline and endline assessments assessed the effect of a nutrition education intervention based on the Health Belief Model on dietary diversity practices among pregnant women in Nuer Zone, Gambella Region, western Ethiopia, from March to June 2026. Nuer Zone is located in the western lowlands of Ethiopia

at 876 kilometers from Addis Ababa. It is found at the longitude of 8°10'N to 8.167°N and latitude of 33°34'E to 33.567°E with an elevation of 400-340 meters above sea level. The zone is rural, with populations predominantly agro-pastoral, relying on traditional crop cultivation, livestock rearing, and fishing for livelihoods. Subsistence farming lacking crop diversity is widely practiced in the zone, with maize as the primary food crop. In addition, the food system is largely weak because of transportation challenges and the lack of local food markets, contributing to poor dietary diversity and undernutrition. Administratively, Nuer Zone comprises five districts and 121 kebeles (smallest administrative units). According to the 2026 projection, it has a total population of 206,598, including 53,922 women of reproductive age and 6,198 pregnant women. In terms of healthcare services, the zone has one primary hospital, eight health centers, and 47 health posts.

Study Populations, Inclusion, and Exclusion Criteria

The source population comprises all pregnant women residing in rural western Ethiopia. The study population includes pregnant women identified through community-based screening in selected districts of the Nuer zone. Pregnant women in their first or second trimester (up to 16 weeks) were eligible, as the intervention was designed to be implemented before delivery. Pregnant women at gestational age greater than 16 weeks, women who require special diets (or nutrition therapy) for any medical condition that may interfere with dietary intake, pregnant women identified as having deliberate plans to emigrate from the study area before the intervention period, and those

who lived in the study setting for less than 6 weeks were excluded from the study.

Sample Size Determination

Sample size was calculated using G*Power version 3.1.9.7 [22] for a two-sample t-test (independent means). With $\alpha = 0.05$, power = 0.80, an allocation ratio of 1:1, and an effect size of 0.4, we obtained a sample of 156. Accounting for the design effect of 2 and a 10% non-response rate, the final sample size becomes 328 (164 participants per arm). Effect size was considered based on the findings of a cluster-randomized trial in West Gojam zone, Ethiopia, with a mean Dietary Diversity Score (DDS) of 5.4 ± 1.8 in the intervention compared to 4.5 ± 1.6 in the control group at endline, yielding a Cohen's d effect size of 0.4 [8].

Sampling Procedure and Randomization

A multi-stage stratified sampling technique was employed to recruit study subjects. Initially, four districts were selected from the five districts of the Nuer zone using a pseudo-random number generator. In the second stage, the selected districts (Lare, Jikaw, Makuety, and Wanthoa) were stratified into pairs based on geographic proximity and similar population density and health service availability, then randomly assigned to either the intervention or control arm. In the third stage, 20% of kebeles (representative clusters) were selected from each district using a random number generator, making a total of 22 kebeles in both arms. A household screening (pre-study household survey) was carried out in these kebeles to identify eligible pregnant women and establish a sampling frame. Finally, the study used systematic random sampling to select participants.

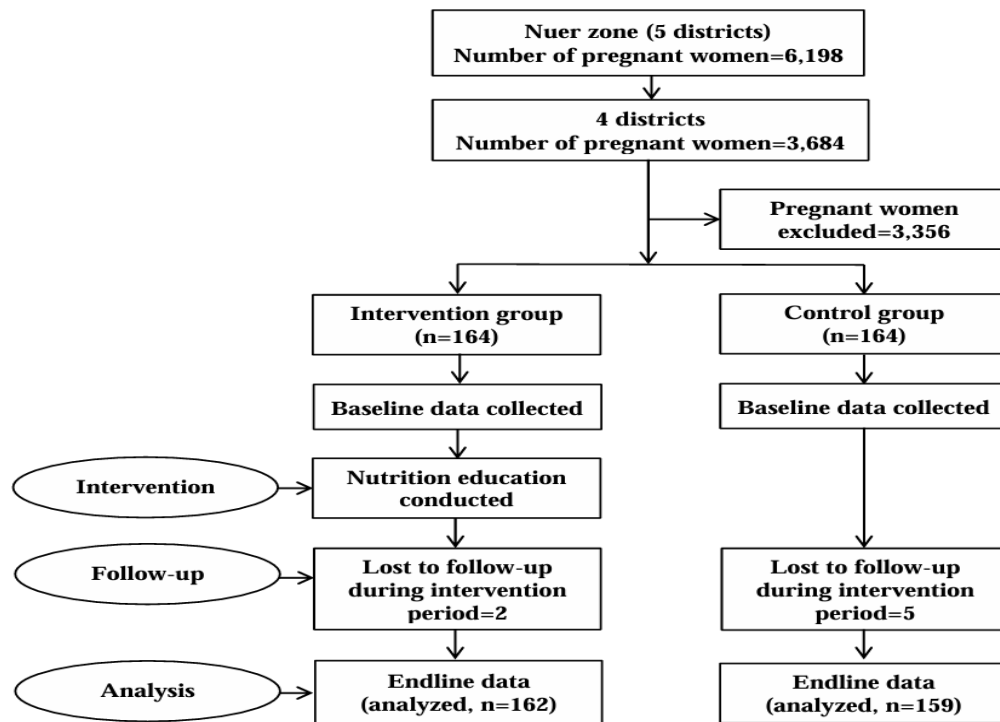


Figure 2. Flowchart of Study Participants Through the Phases of Intervention in Rural Western Ethiopia.

Blinding

Data collectors and outcome assessors were blinded to group allocation to minimize measurement bias. Although participants could not be blinded to the intervention because of its behavioral nature, both groups were blinded to the specific hypotheses and outcome measures to reduce performance bias.

Theoretical Framework

This study applied the Health Belief Model as the theoretical framework to guide the nutrition education intervention. The HBM posits that an individual's beliefs about the risks and consequences of a health condition, combined with beliefs about the effectiveness of recommended actions, predict engagement in health-promoting behaviors [19]. The intervention will focus on six HBM constructs: perceived susceptibility to undernutrition during pregnancy, perceived severity of undernutrition during pregnancy, perceived benefits of dietary diversity, perceived barriers to dietary diversity practice, self-efficacy, and cues to action. The study does not aim to test HBM itself but rather uses its foundational

behavioral frameworks to design and deliver the educational content.

Nutrition Education Intervention

Pregnant women in the intervention arm received monthly nutrition education for three consecutive months. Educational resources such as manuals, leaflets, brochures, and counseling cards were developed based on the dietary and nutritional recommendations of the World Health Organization, the Food and Agriculture Organization [1], and the Ethiopian Ministry of Health [10]. The education module covered: risks of undernutrition in pregnancy, physiological needs of pregnancy, short- and long-term health, economic and social consequences of undernutrition for mothers and children, benefits of dietary diversity and pregnancy weight gain, food groups and their nutrient contents (emphasizing locally available foods), mixed dishes and serving sizes, and recommended eating patterns, food taboos and misconceptions, food hygiene and safety, and the benefits of iodized salt and iron-folic acid supplementation. Each education session

lasted three hours and was delivered in the local (“Nuer”) language using interactive methods such as discussions, brainstorming, group learning, demonstrations, and role plays to enhance engagement and retention. The methodologies and structures followed the guidance in the Training of Trainers Manual for Counseling on Maternal, Infant, and Young Child Nutrition [23]. Two health professionals with bachelor's degrees and two with master's degrees were recruited as educators and supervisors based on their experience and proficiency in the local language. They received a five-day training on the intervention content and delivery methods. In addition, community health extension workers received a one-day training and conducted home-to-home visits every 15 days to provide individual nutrition counseling for 30–60 minutes per session. During these visits, they identified and discussed practical challenges to dietary diversity and provided tailored support to enhance self-efficacy. The intervention was delivered over three consecutive months, and endline data were collected one month after the final education session to assess sustained behavior change.

Intervention Fidelity

Fidelity of the intervention was ensured using the five best-practice elements defined by the National Institutes of Health Behavior Change Consortium [22]: (i) ensuring that the intervention dose was uniform across all participants by following a standardized education manual that outlined learning activities and time allocation; (ii) standardizing interventionist training through a structured manual that defined key elements and procedures; (iii) monitoring intervention delivery using a structured field supervision guide and session scripts; (iv) evaluating participants' understanding through pre- and post-tests in each session; and (v) ensuring participants use the skills taught through reinforcement during home visits.

Interventionist fidelity was assessed using structured observation checklists completed by supervisors for 90% of education sessions ($n = 54$ of 60) and 85% of home visits ($n = 102$ of 120). Fidelity scores (percentage of checklist items completed as planned) averaged 87.3% ($SD = 6.2$) for education sessions and 85.6% ($SD = 7.1$) for home visits. Inter-educator agreement was assessed by having two supervisors independently rate 10% of sessions, yielding Cohen's $\kappa = 0.82$ (95% CI: 0.74–0.89), indicating high agreement.

Variables and Operational Definitions

Dietary Diversity Practice was assessed using the Minimum Dietary Diversity for Women (MDD-W) indicator, based on a 24-hour dietary recall. MDD-W is a food group diversity indicator used as a proxy for micronutrient adequacy of diets of women of reproductive age. It uses ten food groups namely (1) grains, white roots and tubers, and plantains, (2) pulses: beans, peas, and lentils, (3) nuts and seeds, (4) dairy: milk and milk products; (5) meat, poultry, and fish, (6) eggs, (7) dark green leafy vegetables, (8) vitamin A-rich fruits and vegetables, (9) other vegetables, and (10) other fruits. Participants recalled all foods (ingredients) they ate in the previous 24 hours. Each food group consumed was scored as 1, and scores were summed to obtain the Dietary Diversity Score (DDS), ranging from 0 to 10. A DDS of 5 or more indicates adequate dietary diversity, while a score below 5 indicates inadequate diversity. Consuming at least five of the ten food groups reflects higher nutrient intake than the average requirement for 11 micronutrients of public health relevance, such as calcium, folate, iron, zinc, vitamin A, thiamine, riboflavin, niacin, vitamin B6, vitamin B12, and vitamin C [24]. Only foods consumed in quantities of at least 15 grams (“one tablespoon”) were counted in the food group indicator to avoid falsely inflating the dietary diversity score.

Health Belief Model Constructs were measured using 27-item Likert-scale questionnaire, adapted from validated instruments [25, 26], covering perceived susceptibility (4 items), perceived severity (4 items), perceived benefits (4 items), perceived barriers (5 items), self-efficacy (4 items), and cues to action (6 items). Responses were scored on a five-point scale (strongly disagree to strongly agree, very unlikely to very likely) to rate participants' perceptions and beliefs. Scores for each construct were summed and categorized into tertiles, with the highest tertile indicating a higher level for the construct. Higher perceived susceptibility, perceived severity, perceived benefits, self-efficacy, and cues to action are associated with a higher likelihood of participants engaging and achieving desired behavior outcomes ("adequate dietary diversity"), whereas higher perceived barriers are associated with a lower likelihood of adopting behavior and achieving outcomes [27].

Household Food Insecurity was assessed using the standard Household Food Insecurity Access Scale (HFIAS) [28], comprising nine occurrence questions and nine frequency questions. Occurrence questions are dichotomous (Yes/No) and ask whether a household experienced any food insecurity (access)- related conditions in the last four months. Each occurrence question specifies "lack of resource" as the reason for food insecurity to ensure the measure excludes food deprivation conditions associated with behaviors such as dieting to lose weight, fasting for religious reasons, or food shortages for any reason other than resource constraints. The occurrence or experience of a food insecurity (access) related condition is coded 1, and non-occurrence is coded 0. Households experiencing at least one food insecurity condition in the past four weeks were classified as food insecure.

Household Wealth Index was measured using an adapted version of the International Wealth Index (IWI), covering household assets, housing quality, water source, and sanitation facilities [29]. The IWI scale is an asset-based index used to measure households' long-term economic status and living standards in low-and middle-income countries [29]. A household owning more expensive consumer durables, a better-quality house, and having access to basic services has a higher level of material well-being [29]. The tool comprised 22 questions. 20 of these are dichotomous, asking whether a household owns defined assets or goods, such as consumer durables. Two questions assessed the quality of the household's water supply and toilet facility. Dichotomous questions are scored as 1 (yes) or 0 (no). The quality of the toilet facility is scored as low quality (1) for traditional pit latrines, hanging toilets, and no toilet facility; middle quality (2) for public toilets and improved pit latrines; and high quality (3) for private flush toilets. Household water supply quality was scored as low quality (1) for unprotected wells, boreholes, springs, and surface water sources; middle quality (2) for public taps, protected wells, and tanker trucks; and high quality (3) for bottled water or water piped into dwellings. Principal component analysis was used to derive weights, and scores were categorized into quintiles: first wealth quintile (poorest household), second quintile (poor household), third quintile (medium household), fourth quintile (wealthy household), and fifth wealth quintile (wealthiest household).

Nutrition Knowledge was measured using 11 dichotomous questions (yes/no), coded as 1 for a correct response and 0 for an incorrect response. Knowledge scores were converted into tertiles, with the highest tertiles indicating good nutrition knowledge, the middle tertiles indicating medium nutrition knowledge, and the lowest tertiles indicating poor nutrition knowledge.

Data Collection Instruments and Procedure

A pre-tested, structured interviewer-administered questionnaire adapted from the literature was used to collect data [30]. The questionnaire comprises nine sections covering demographic and socioeconomic characteristics, obstetric history, dietary diversity, HBM constructs, nutrition knowledge, eating habits, food taboos, household food insecurity, and wealth index. A 24-hour 'open' dietary recall was used to capture all foods consumed in meals and snacks over the previous day. Mixed dishes were disaggregated into their ingredient components, and only ingredients consumed in quantities ≥ 15 grams were counted in the MDD-W food groups. Four data collectors with bachelor's degrees in public health nutrition and two supervisors with master's degrees in the same field were recruited and trained. Data collection occurred in three phases: (1) a pre-study household survey to identify eligible participants and create the sampling frame, (2) baseline data collection, conducted immediately before the intervention, and (3) endline data collection, conducted one month after the final education session to assess outcome variables (DDS, MUAC, HBM constructs, nutrition knowledge, and eating habits).

Data Quality Assurance

Independent language experts translated the questionnaire into the local "Nuer" language and back-translated it into English to ensure conceptual equivalence. Data collectors and supervisors received five days of training on interviewing techniques, 24-hour dietary recall procedures, food group classification, operationalizing serving sizes, mixed dishes, and anthropometric measurements.

The questionnaire was pre-tested on 5% of the sample in a non-study district. Internal consistency was assessed using Cronbach's alpha, which ranged from 0.72 to 0.89 across

the HBM subscales, exceeding the target threshold of 0.7. Content validity was assessed using Lawshe's Content Validity Ratio, with values ranging from 0.81 to 0.95 (target ≥ 0.78). Face validity was assessed using Cohen's Kappa, yielding values of 0.65 to 0.78 (target ≥ 0.60). Confirmatory factor analysis was performed to validate the HBM constructs, with goodness-of-fit indices ranging from 0.91 to 0.95 (target ≥ 0.9).

To prevent recall bias in the 24-hour dietary recall, a comfortable and neutral environment for the interview was ensured, rapport was established, and sufficient time was allowed for subjects to think without rushing to enhance their memory recall. During data collection, data collectors checked each questionnaire for completeness, and supervisors verified completeness and accuracy daily.

Statistical Analysis

Data were collected using an online Kobo Toolbox form on Android devices and exported to SPSS version 25.0 for analysis. Descriptive statistics (means, standard deviations, frequencies, percentages) were computed for all variables. Normality of continuous variables was assessed using the Kolmogorov-Smirnov test. Baseline comparability between intervention and control groups was assessed using chi-square tests (for categorical variables) and independent t-tests (for continuous variables). To assess the effect of the nutrition education intervention on dietary diversity over time, Generalized Estimating Equations (GEE) were used. This approach was chosen to account for the inherent correlation between the two repeated measurements (baseline and endline) taken from the same pregnant woman, while providing population-averaged estimates that are directly interpretable as the average intervention effect across the study sample. The primary outcome, Dietary Diversity Score (DDS), is a count variable representing the

number of food groups consumed out of the possible ten. Given its discrete, bounded nature and the likelihood of increasing variance with higher mean values, a distribution that correctly models the data-generating process was selected with due care.

To determine the most appropriate distribution for the count outcome, we initially fitted a Poisson GEE model and assessed the overdispersion parameter (calculated as the Pearson chi-square statistic divided by its degrees of freedom). This parameter indicated significant overdispersion (value = 1.47), meaning the variance in DDS substantially exceeded the mean, which is common in dietary data where some women consume very few foods while others consume many. Consequently, the Poisson distribution was rejected in favor of the Negative Binomial distribution, which includes an additional dispersion parameter to explicitly model this extra-variability and ensure correctly estimated standard errors. A log link function was employed, and the model was specified with an exchangeable working correlation matrix. This structure assumes a constant correlation between the two time points for each participant, which is a parsimonious and appropriate choice with only two repeated measures; moreover, the use of robust (sandwich) standard errors ensures that inference remains valid even if this correlation structure is slightly misspecified. The primary analytic model was adjusted for a set of pre-specified baseline covariates to control for potential confounding and to improve the precision of the intervention effect estimate. These covariates included maternal age, education level, household wealth index quintiles, family size, parity, and baseline DDS.

The primary parameter of interest was the interaction between Time and Group (Time $\times$ Group), which directly estimates the difference-in-differences (DiD) that is, the additional change in DDS from baseline to

endline in the intervention group relative to the control group. A series of diagnostic checks was performed to validate the assumptions underlying the GEE model. The GEE model was specified with the 22 kebeles as the highest-level clustering variable to adjust for the intra-cluster correlation inherent in the study design, while the subject was defined as each participant's unique identifier to account for the correlation between repeated measurements. The mean-variance relationship was assessed by plotting standardized Pearson residuals against fitted values, which revealed no systematic patterns, confirming that the Negative Binomial variance function adequately captured the heteroscedasticity. Multicollinearity among continuous predictors was examined using Variance Inflation Factors (VIFs), all of which were below 2.0, indicating no problematic collinearity. Influential observations were screened using Cook's distance; no values exceeded the conventional threshold of $4/n$, suggesting that individual participants did not disproportionately influence the overall estimates. Regarding missing data, fewer than 5% of observations were incomplete. Baseline characteristics between participants who completed follow-up and those lost to follow-up were compared; no statistically significant differences observed, supporting the assumption that missingness was unrelated to the outcome after accounting for observed covariates (missing at random).

Consequently, GEE provides valid estimates under these conditions. All coefficients from the Negative Binomial Model were exponentiated to present Incidence Rate Ratios (IRR), which represent the multiplicative change in the expected DDS count. Hypothesis testing was conducted using Wald chi-square tests with a two-sided significance level of $\alpha=0.05$. To aid interpretation, estimated marginal means (EMMeans) were computed on the response scale for each group at each time point, adjusted for all covariates, and within-group

changes over time were compared using pairwise contrasts with the Least Significant Difference (LSD) adjustment. All analyses were performed using IBM SPSS Statistics for Windows, Version 25 (IBM Corp., Armonk, NY, USA), using the Generalized Estimating Equations procedure (GENLIN) with a Negative Binomial distribution and a log link.

Results

Baseline Participants Characteristics and Comparability

The flowchart of study participants through the phases of intervention is illustrated in Figure 2. Of 328 pregnant women enrolled in the study (164 per arm), 321 (97.9%) completed follow-up (intervention 162, control 159); attrition was unrelated to

baseline characteristics (all $P > 0.05$). Table 1 demonstrates complete baseline equivalence across all sociodemographic, socioeconomic, and nutritional variables (P values: 0.168–0.957), confirming successful randomization. The sample predominantly aged 25–34 years (~60%), with similar marital status and family size distribution across arms. Approximately 50% were food insecure, 72–76% had inadequate dietary diversity, and 72% had low-to-medium nutrition knowledge. The mean gestational age at baseline was comparable in intervention and control groups (13.76 vs 14.61 weeks, respectively). This homogeneity ensures that post-intervention differences are attributable to the intervention (Table 1).

Table 1. Baseline Sociodemographic and Economic Characteristics of Participants by Study Group in Nuer Zone, Gambella Region, Western Ethiopia, 2026

Characteristics	Category	Intervention	Control	P-value
		N (%)	N (%)	
Age (years)	≤24	43 (26.2)	46 (28.0)	0.487
	25–34	98 (59.8)	102 (62.2)	
	≥35	23 (14.0)	16 (9.80)	
Marital status	Married & live together	57 (34.8)	55 (33.5)	0.937
	Separated	56 (34.1)	55 (33.5)	
	Divorced	51 (31.1)	54 (32.9)	
Education of respondent	College and above	50 (30.5)	47 (28.7)	0.957
	Secondary (9–12)	36 (22.0)	38 (23.2)	
	Primary (1–8)	42 (25.6)	40 (24.4)	
	No formal education	36 (22.0)	39 (23.8)	
Occupation of respondent	Employee	39 (23.8)	44 (26.8)	0.254
	Merchant (trader)	41 (25.0)	36 (22.0)	
	Farmer	39 (23.8)	51 (31.1)	
	Daily laborer	45 (27.4)	33 (20.1)	
Education of husband	College and above	49 (29.9)	37 (22.6)	0.359
	Secondary (9–12)	37 (22.6)	37 (22.6)	
	Primary (1–8)	34 (20.7)	45 (27.4)	
	No formal education	44 (26.8)	45 (27.4)	
Occupation of husband	Employee	40 (24.4)	38 (23.2)	0.168
	Merchant (trader)	49 (29.9)	34 (20.7)	
	Farmer	37 (22.6)	40 (24.4)	
	Daily laborer	38 (23.2)	52 (31.7)	

Family size	<5 (small)	74 (45.1)	71 (43.3)	0.739
	≥5 (large)	90 (54.9)	93 (56.7)	
Nutrition knowledge	Low	72 (43.9)	77 (47.0)	0.833
	Medium	47 (28.7)	46 (28.0)	
	High	45 (27.4)	41 (25.0)	
Household food security	Food secure	88 (53.7)	79 (48.2)	0.32
	Food insecure	76 (46.3)	85 (51.8)	
Dietary diversity	Inadequate	124 (75.9%)	120 (73.0)	0.542
	Adequate	40 (24.1%)	44 (27.0)	
Mean gestational age		13.76	14.61	0.10

Correlation of HBM Constructs with Dietary Diversity

Table 2 presents the independent t-test comparisons of Health Belief Model constructs between the intervention and control groups at baseline and endline. At baseline, no statistically significant difference was observed across any of the six HBM constructs (all $p > 0.05$), confirming complete randomization and group comparability before the intervention. At endline, however, the intervention group demonstrated significantly higher scores than the control group on perceived susceptibility ($p < 0.001$, Mean difference = +2.68, 95% CI: 2.29–3.07), perceived severity ($p < 0.001$, Mean

difference = +3.59, 95% CI: 3.20–3.98), perceived benefits ($p < 0.001$, Mean difference = +2.47, 95% CI: 2.06–2.88), self-efficacy ($p < 0.001$, Mean difference = +1.49, 95% CI: 1.04–1.94), and cues to action ($p < 0.001$, Mean difference = +3.56, 95% CI: 3.05–4.07). The largest intervention effect was observed on perceived severity, where the intervention group scored +3.59 points higher than the control group. Conversely, the intervention group reported significantly fewer perceived barriers to dietary diversity than the control group ($p < 0.001$, Mean difference = –4.58, 95% CI: –4.95 to –4.21) (Table 2).

Table 2. Baseline Comparability and Endline Intervention Effects on Health Belief Model Constructs by Study Group in Nuer Zone, Gambella Region, Western Ethiopia, 2026

Construct	Time	Intervention	Control	t	P-value	Mean Difference	Effect Size
		Mean (SD)	Mean (SD)			(95% CI)	
Perceived Susceptibility	Baseline	11.38 (3.01)	11.48 (3.13)	0.41	0.68	–0.10 (–0.58, 0.38)	0.03
	End line	13.95 (3.05)	11.27 (1.92)	13.4	<0.001	2.68 (2.29, 3.07)	1.06
Perceived Severity	Baseline	13.04 (3.19)	12.83 (3.33)	0.82	0.414	0.21 (–0.29, 0.71)	0.06
	End line	16.82 (2.90)	13.23 (2.03)	18.2	<0.001	3.59 (3.20, 3.98)	1.45
Perceived Benefits	Baseline	11.35 (2.99)	11.48 (3.13)	0.54	0.592	–0.13 (–0.61, 0.35)	0.04
	End line	17.32 (2.99)	14.85 (2.22)	11.9	<0.001	2.47 (2.06, 2.88)	0.94
Perceived Barriers	Baseline	14.15 (3.11)	14.24 (2.98)	0.37	0.709	–0.09 (–0.56, 0.38)	0.03
	End line	9.36 (2.85)	13.94 (1.79)	24.4	<0.001	–4.58 (–4.95, –4.21)	1.94
Self-Efficacy	Baseline	10.39 (2.36)	10.16 (1.87)	1.37	0.172	0.23 (–0.10, 0.56)	0.11
	End line	12.79 (2.99)	11.30 (2.86)	6.45	<0.001	1.49 (1.04, 1.94)	0.51
Cues to Action	Baseline	11.97 (3.03)	12.03 (3.65)	0.23	0.821	–0.06 (–0.58, 0.46)	0.02
	End line	15.91 (3.73)	12.35 (2.75)	13.8	<0.001	3.56 (3.05, 4.07)	1.10

CI: Confidence Interval, SD: Standard Deviation

Effect of Nutrition Education Intervention on Dietary Diversity

Endline dietary diversity data showed a considerable between-group difference in outcomes. At baseline, intervention and control groups exhibited comparable proportions of inadequate dietary diversity (75.3% and 73.0%, respectively). By the endline assessment, the proportion of participants achieving adequate dietary diversity in the intervention group rose from 24.7% to 73.5%. Over the same interval, the control group declined in adequate dietary diversity, falling from 27.0% to 6.9%. This endline disparity, representing an absolute difference of 66.6 percentage points in favor of the intervention, suggests that the intervention was associated with improved dietary outcomes relative to baseline. Moreover, the

concurrent deterioration observed in the control group, potentially attributable to external factors such as seasonal food scarcity, highlights a possible protective effect of the intervention against such contextual influences. The period from March to June (when this study was carried out) marks the transition from the post-harvest spring season to early summer before the main harvest, with a seasonal shortage of fresh produce and a hunger gap in the study setting. Collectively, these results indicate that the intervention is associated with a notable improvement in dietary diversity within this study population. These observations support consideration of this strategy for broader implementation, although further evaluation across varied contexts is prudent (Table 3).

Table 3. Dietary Diversity Practice of Pregnant Women Over the Follow-up Period in Nuer Zone, Gambella Region, Western Ethiopia, 2026

Variable	Study Period	Category	Intervention	Control
			N (%)	N (%)
DDS	Baseline	Inadequate dietary diversity	122 (75.3%)	116 (73.0%)
		Adequate dietary diversity	40 (24.7%)	43 (27.0%)
	End line	Inadequate dietary diversity	43 (26.5%)	148 (93.1%)
		Adequate dietary diversity	119 (73.5%)	11 (6.9%)

DDS: Dietary Diversity Score

Observing the group Dietary Diversity Scores (DDS), the intervention and control groups were statistically comparable at baseline: the intervention group recorded a mean DDS of 3.47 (SD = 1.093), while the control group recorded 3.57 (SD = 1.052); the between-group mean difference was -0.103 (SE = 0.120), and the corresponding t-test yielded a p-value of 0.390, confirming no statistically significant difference at the study's outset. At the endline, the mean DDS of the intervention group rose to 4.52 (SD = 0.879), whereas the control group's score declined to 3.06 (SD = 0.847), with a between-group mean difference of 1.456 (SE = 0.096), a t-value of 15.102, and a p-value < 0.01, representing a

statistically significant difference in favor of the intervention group. Examining within-group changes from baseline to endline, the intervention group demonstrated a mean DDS increase of +1.05 points, while the control group exhibited a mean decrease of -0.51 points, yielding a Difference-in-Differences (DiD) estimate of 1.56, which was also statistically significant (p-value < 0.01). Collectively, these results suggest that the intervention was associated with a statistically significant net improvement in dietary diversity scores relative to the control group, and the concurrent decline in scores among the control group further supports the observed effect (Table 4).

Table 4. Differences in Mean Dietary Diversity Scores by Group Over the Study Period in Nuer Zone, Gambella Region, Western Ethiopia, 2026

Variable	Study Period	Intervention	Control	t-test	Mean Difference	P-value
		Mean $\pm$ SD	Mean $\pm$ SD		(Intervention – Control) $\pm$ SE	
DDS	Baseline	3.47 $\pm$ 1.093	3.57 $\pm$ 1.052	–0.861	–0.103 $\pm$ 0.120	0.39
	End line	4.52 $\pm$ 0.879	3.06 $\pm$ 0.847	15.1	1.456 $\pm$ 0.096	<0.01
	Difference (EL – BL)	1.05	–0.51	–	1.56 (DiD)	< 0.01

BL: Baseline, DDS: Dietary Diversity Score, EL: End-line, SD: Standard Deviation, SE: Standard Error

Because DDS is a count variable and showed overdispersion (dispersion parameter = 1.47), we fitted the GEE model with a Negative Binomial distribution and a log link. The fully adjusted model revealed a significant main effect of Time (IRR = 0.738, 95% CI: 0.699–0.780) and Group (IRR = 0.735, 95% CI: 0.691–0.782), alongside a highly significant positive Time $\times$ Group interaction (IRR = 1.425, 95% CI: 1.322–1.535, p < 0.001). The intervention group experienced a 35.5% relative increase in DDS from baseline to endline, whereas the control group experienced a 4.9% relative decline. Consequently, the nutrition education intervention produced a 42.5% greater relative increase in dietary diversity than the control group. Among the covariates, baseline DDS exhibited a strong, graded regression-to-the-mean effect: women with DDS of 2, 3, 4, and 5 had significantly lower endline scores compared to those with baseline score of 6 (IRRs = 0.553, 0.688, 0.813, and 0.928, respectively, all p < 0.01). Good nutrition knowledge was independently associated with higher DDS (IRR = 1.065, 95% CI: 1.027–1.105, p = 0.001). Education was

also significantly associated with DDS; women with primary (IRR = 0.943, p = 0.004) and secondary education (IRR = 0.953, p = 0.040) had lower DDS compared to those with tertiary education. Family size showed a marginal positive association that did not reach statistical significance (IRR = 1.025, 95% CI: 0.998–1.053, p = 0.065), while home garden availability was not significantly associated with DDS (IRR = 1.014, p = 0.298). None of the other sociodemographic factors, including age, household wealth, parity, food insecurity, or ANC attendance, was significantly associated with DDS (as all 95% confidence intervals crossed 1.00). Overall, these findings demonstrate that the intervention produced a robust and statistically significant improvement in dietary diversity, independent of baseline dietary status, food insecurity, and all measured socio-demographic characteristics. Identifying nutrition knowledge as a strong independent predictor, alongside the graded effect of baseline DDS, underscores the importance of targeted education and the need to account for regression to the mean in intervention studies (Table 5).

Table 5. Generalized Estimating Equation of the Intervention Effect on Dietary Diversity Practices of the Pregnant Women in Nuer Zone, Gambella Region, Western Ethiopia, 2026

Parameter	β	SE	IRR	95% CI
(Intercept)	1.841	0.043	6.305	(5.798, 6.855)
Time (End line vs Baseline [Ref])	–0.303	0.028	0.738	(0.699, 0.780)
Group (Intervention vs Control [Ref])	–0.308	0.032	0.735	(0.691, 0.782)
Time $\times$ Group	0.354	0.038	1.425	(1.322, 1.535)
Age category (Ref: ≥ 35 years)	–	–	1	–

15–24 years	0.011	0.024	1.011	(0.964, 1.060)
25–34 years	0.006	0.02	1.006	(0.968, 1.046)
Education (Ref: Tertiary)	–	–	1	–
No formal education	–0.036	0.024	0.964	(0.921, 1.010)
Primary	–0.059	0.021	0.943	(0.905, 0.982)
Secondary	–0.048	0.023	0.953	(0.911, 0.998)
Family size (Ref: large)	0.025	0.014	1.025	(0.998, 1.053)
Household wealth (Ref: Richest)	–	–	1	–
Poorest	–0.035	0.019	0.966	(0.929, 1.003)
Poorer	–0.037	0.02	0.964	(0.927, 1.002)
Middle	–0.039	0.022	0.962	(0.922, 1.004)
Richer	–0.031	0.019	0.97	(0.935, 1.006)
Parity (Ref: Grand multipara)	–	–	1	–
Nulipara	–0.002	0.026	0.998	(0.948, 1.050)
Multipara	0.018	0.02	1.018	(0.979, 1.059)
Household food insecurity (Food Insecure vs Secure [Ref])	–0.008	0.018	0.992	(0.958, 1.026)
ANC attendance (Ref: No)	–0.027	0.021	0.974	(0.935, 1.014)
Nutrition knowledge (Ref: Poor)	0.063	0.019	1.065	(1.027, 1.105)
Home garden available (Ref: No)	0.014	0.014	1.014	(0.988, 1.042)
Baseline DDS (Ref: Score = 6)	–	–	1	–
Score = 2	–0.593	0.031	0.553	(0.520, 0.587)
Score = 3	–0.375	0.027	0.688	(0.653, 0.725)
Score = 4	–0.207	0.03	0.813	(0.767, 0.861)
Score = 5	–0.075	0.027	0.928	(0.879, 0.979)

ANC: Antenatal Care, CI: Confidence Interval, DDS: Dietary Diversity Score, IRR: Incidence Rate Ratio, Ref: Reference Category, SE: Standard Error.

Mediation of HBM Pathways Influencing Dietary Diversity

To investigate the mechanisms through which the nutrition education intervention influenced dietary diversity, a parallel multiple mediation analysis was conducted using the product-of-coefficients method with 5,000 bootstrap resamples to estimate indirect effects (IE) and their 95% confidence intervals. The analysis tested whether changes in the six HBM constructs: perceived susceptibility, severity, benefits, barriers, self-efficacy, and cues to action mediated the intervention's effect on endline DDS, adjusting for baseline covariates. The total effect of the intervention on dietary diversity was 0.474 (95% CI: 0.312–0.636; $p < 0.001$). After controlling

for all mediators simultaneously, the direct effect was reduced to 0.096 (95% CI: –0.028 to 0.220; $p = 0.128$), indicating full mediation. The total indirect effect through all mediators was 0.378 (95% CI: 0.251–0.505), accounting for 79.7% of the total effect. Self-efficacy was the strongest mediator, accounting for 38% of the total effect (IE = 0.180, 95% CI: 0.112–0.258). Perceived benefits (IE = 0.076, 95% CI: 0.032–0.124; 16%) and perceived barriers (IE = 0.077, 95% CI: 0.028–0.131; 16%) also emerged as significant mediators. Perceived susceptibility had a small but significant mediating effect (IE = 0.018, 95% CI: 0.005–0.035; 4%). In contrast, perceived severity (IE = 0.008, 95% CI: –0.002–0.020) and cues to action (IE = 0.019, 95% CI: –0.004–0.045)

did not significantly mediate the intervention effect, as their confidence intervals included

zero (Figure 3, Table 6).

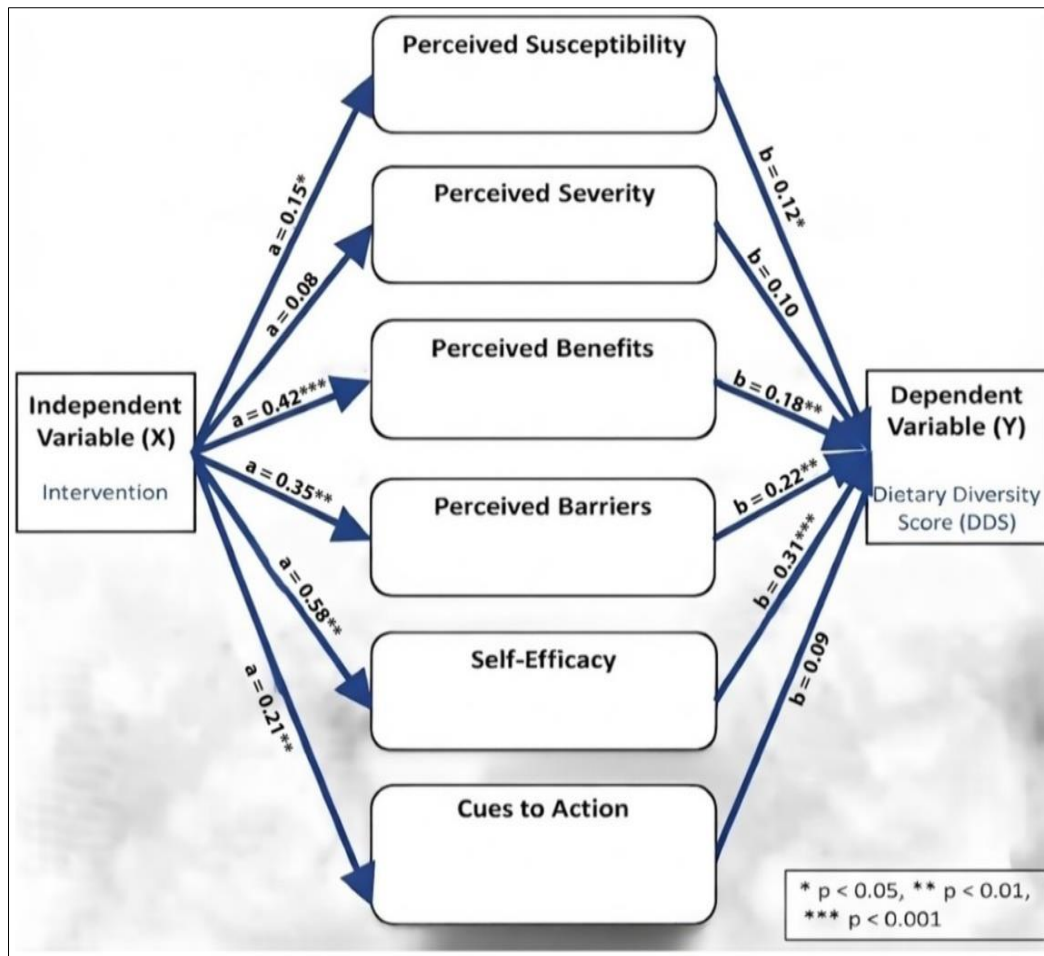


Figure 3. Parallel Multiple Mediation Models of Health Belief Model Constructs

Table 6. Mediation Analysis of Health Belief Model Pathways in a Nutrition Education Intervention to Improve Dietary Diversity among Pregnant Women in Nuer Zone, Gambella Region, Western Ethiopia, 2026

Mediator (M)	Path a	Path b	Indirect Effect	95% CI	Proportion Mediated
	(X→M)	(M→Y)	(a×b)		
Perceived Susceptibility	0.15*	0.12*	0.018*	(0.005, 0.035)	4%
Perceived Severity	0.08	0.1	0.008	(-0.002, 0.020)	—
Perceived Benefits	0.42***	0.18**	0.076**	(0.032, 0.124)	16%
Perceived Barriers	-0.35***	-0.22**	0.077**	(0.028, 0.131)	16%
Self-Efficacy	0.58***	0.31***	0.180***	(0.112, 0.258)	38%
Cues to Action	0.21**	0.09	0.019	(-0.004, 0.045)	—

*p-value < 0.05, **p-value < 0.01, ***p-value < 0.001

Per-Protocol Analysis of Intervention Effect on Dietary Diversity

To complement the primary intention-to-treat analysis, a per-protocol analysis was conducted among women who adhered to the intervention protocol (attended $\geq 50\%$ of education sessions). Of the 164 women in the intervention group, 138 (84.1%) were adherent. In the per-protocol GEE model, the Time $\times$ Group interaction remained highly significant (IRR = 1.385, 95% CI: 1.274–1.507, $p < 0.001$). The intervention group experienced a 33.3% relative increase in DDS from baseline to endline, while the control group experienced a 3.8% relative decline. The net effect was a 38.5% greater relative increase in dietary diversity compared to the control group, slightly attenuated from the intention-to-treat (ITT) estimate of 42.5%.

This consistency, observed in both analytical approaches, confirms the robustness of the intervention's impact. Among the covariates, the graded regression-to-the-mean effect persisted ($p < 0.01$ for all baseline DDS categories). Nutrition knowledge remained a strong independent predictor (IRR = 1.071, 95% CI: 1.029–1.115, $p = 0.001$). Family size was significantly associated with DDS; women from smaller households had 3.3% higher DDS compared to those from larger households (IRR = 1.033, $p = 0.031$), while education showed a borderline association (Primary vs. Tertiary: IRR = 0.954, 95% CI: 0.907–1.002, $p = 0.060$), likely due to the reduced sample size. None of the other covariates were significantly associated with DDS (all $p > 0.05$) (Table 7).

Table 7. Per-Protocol Analysis of the Intervention Effect on Dietary Diversity of Pregnant Women in Nuer Zone, Gambella Region, Western Ethiopia, 2026

Parameter	β	SE	IRR	95% CI	P-value
(Intercept)	1.809	0.045	6.104	(5.584, 6.672)	<0.001
Time (End line vs Baseline [Ref])	-0.288	0.03	0.75	(0.706, 0.795)	<0.001
Group (Intervention vs Control [Ref])	-0.283	0.036	0.753	(0.702, 0.808)	<0.001
Time $\times$ Group	0.326	0.043	1.385	(1.274, 1.507)	<0.001
Age category (Ref: ≥ 35 years)	–	–	1	–	–
15–24 years	0.007	0.028	1.007	(0.954, 1.063)	0.795
25–34 years	0.005	0.022	1.005	(0.962, 1.049)	0.833
Education (Ref: Tertiary)	–	–	1	–	–
No formal education	-0.042	0.028	0.959	(0.907, 1.013)	0.135
Primary	-0.048	0.025	0.954	(0.907, 1.002)	0.06
Secondary	-0.038	0.027	0.963	(0.913, 1.016)	0.17
Family size (Ref: Large)	0.032	0.015	1.033	(1.003, 1.064)	0.031
Household wealth (Ref: Richest)	–	–	1	–	–
Poorest	-0.024	0.022	0.976	(0.934, 1.019)	0.271
Poorer	-0.023	0.023	0.977	(0.934, 1.022)	0.306
Middle	-0.038	0.026	0.963	(0.915, 1.012)	0.137
Richer	-0.031	0.021	0.969	(0.930, 1.010)	0.135
Parity (Ref: Grand multipara)	–	–	1	–	–
Nulipara	0.006	0.029	1.006	(0.950, 1.065)	0.838
Multipara	0.015	0.022	1.016	(0.972, 1.061)	0.49
Household food insecurity (Ref: Food secure)	0.001	0.02	1.001	(0.963, 1.040)	0.972

ANC attendance (Ref: No)	−0.020	0.023	0.98	(0.936, 1.026)	0.389
Nutrition knowledge (Ref: Poor)	0.069	0.02	1.071	(1.029, 1.115)	0.001
Home garden available (Ref: No)	0.005	0.015	1.005	(0.976, 1.035)	0.742
Baseline DDS (Ref: Score = 6)	–	–	1	–	–
Score = 2	−0.609	0.03	0.544	(0.513, 0.577)	<0.001
Score = 3	−0.374	0.026	0.688	(0.654, 0.724)	<0.001
Score = 4	−0.204	0.03	0.816	(0.770, 0.865)	<0.001
Score = 5	−0.072	0.026	0.93	(0.883, 0.980)	0.006

ANC: Antenatal Care, CI: Confidence Interval, DDS: Dietary Diversity Score, IRR: Incidence Rate Ratio, Ref: Reference Category, SE: Standard Error

Subgroup Analysis by Household Food Security Status

A subgroup analysis was conducted to investigate whether the intervention effect varied by household food security status. Food security status was assessed using the Household Food Insecurity Access Scale (HFIAS) at baseline. The intervention effect was significant in both subgroups: Among food-secure women, the intervention led to a 48% greater relative increase in DDS (IRR = 1.480, 95% CI: 1.300–1.685, $p < 0.001$), while the effect was 56% greater relative increase among food-insecure women (IRR = 1.560, 95% CI: 1.401–1.738, $p < 0.001$). To test whether this difference was statistically significant, a three-way interaction term (Time $\times$ Group $\times$ HFIAS) was included in the GEE models. The three-way interaction

was not statistically significant (IRR = 0.936, 95% CI: 0.856–1.023, $p = 0.145$), indicating that the intervention effect did not differ significantly by food security status after adjusting for other covariates: age, education, wealth, parity, family size, and baseline DDS. This suggests that the intervention was equally effective in improving dietary diversity among both food-secure and food-insecure women. Likewise, baseline DDS was significantly associated with endline DDS in both subgroups, consistent with regression to the mean. Among food-secure women, higher baseline DDS was associated with a 23.7% lower endline score (IRR = 0.763, 95% CI: 0.736–0.791, $p < 0.001$), and the effect was the same for the food-insecure subgroup (IRR = 0.761, 95% CI: 0.738–0.785, $p < 0.001$) (Table 8).

Table 8. Subgroup Analysis of Intervention Effect on Dietary Diversity by Food Security Status, Nuer Zone, Gambella Region, Western Ethiopia, 2026

Subgroup	Parameter	β	SE	IRR	95% CI	P value
Interaction Test	Three-Way Interaction (Time $\times$ Group $\times$ HFIAS)	−0.066	0.046	0.936	(0.856, 1.023)	0.145
Food-secure women	Time $\times$ Group	0.392	0.052	1.48	(1.300, 1.685)	<0.001
	Baseline DDS	−0.271	0.018	0.763	(0.736, 0.791)	<0.001
Food-insecure women	Time $\times$ Group	0.445	0.038	1.56	(1.401, 1.738)	<0.001
	Baseline DDS	−0.273	0.016	0.761	(0.738, 0.785)	<0.001

CI: Confidence Interval, IRR: Incidence Rate Ratio, SE: Standard Error

Sensitivity Analysis: Alternative Correlation Structure

To assess the robustness of the primary GEE results to the choice of correlation structure, a sensitivity analysis was conducted. The primary analysis assumed an exchangeable correlation structure. For the sensitivity analysis, the model was refitted using an autoregressive (AR-1) correlation structure, which assumes that measurements closer in time are more highly correlated than those further apart. The sensitivity analysis using an AR-1 correlation structure yielded results consistent with the primary analysis. The Time x Group interaction remained significant (IRR = 1.51, 95% CI: 1.40–1.63, $p < 0.001$), which was comparable to the primary estimate of IRR = 1.52 (95% CI: 1.41–1.65). The direction, magnitude, and statistical significance of the intervention effect did not change materially. This confirms that the primary findings are robust to the choice of correlation structure in the GEE model.

Discussion

This cluster-randomized controlled trial assessed the effect of a Health Belief Model (HBM)-based nutrition education intervention on dietary diversity practices among pregnant women in rural western Ethiopia. The intervention led to a statistically significant and clinically meaningful improvement in dietary diversity, with a 42.5% greater relative increase in the dietary diversity score in the intervention group compared to the control group. In descriptive analyses, the proportion of women achieving adequate dietary diversity rose from 24.7% to 73.5% in the intervention arm but declined from 27.0% to 6.9% in the control arm over the same period, consistent with the adjusted GEE model results. These findings provide robust evidence that theory-based nutrition education can substantially improve maternal dietary practices, even in remote, resource-limited settings. The

observed effect size aligns closely with findings from similar trials in Ethiopia. A cluster-randomized controlled trial conducted in Southeast Ethiopia reported that pregnant women receiving HBM-based education were significantly more likely to achieve adequate dietary diversity compared to controls [31]. Another cluster-randomized controlled trial in Northeast Ethiopia revealed that providing nutrition education based on the Health Belief Model improved nutritional knowledge and dietary practices among pregnant women [9]. Similarly, a quasi-experimental study in rural Southwest Ethiopia found that theory-based nutrition education, combined with male involvement, improved dietary diversity scores among pregnant women [32].

A systematic review and meta-analysis of nutrition education interventions in Ethiopia reported that longer interventions of five or more months yield a larger effect [33]. While our intervention was delivered over three months shorter than the duration identified in that review, the magnitude of improvement observed in this study indicates that a moderate-duration, intensively delivered intervention (combining monthly group sessions with bi-weekly home visits) produces substantial behavioral change. This suggests that intervention intensity and reinforcement frequency may partially compensate for shorter overall duration, particularly when theoretical frameworks like the HBM address multiple cognitive and practical determinants of behavior simultaneously.

Beyond the overall effect size, it is important to distinguish the intervention's true impact from a statistical phenomenon known as regression to the mean (RTM). In this study, two patterns were observed. First, the intervention group demonstrated a substantial improvement in dietary diversity relative to the control group, indicating a genuine program effect. Second, an inverse relationship was observed between baseline and endline dietary diversity scores: women who started with

higher dietary diversity tended to have lower scores at follow-up. This is consistent with RTM, whereby extreme baseline values naturally move toward the average upon repeated measurement. A similar pattern emerged in a large cohort study of Japanese adults, where those with high baseline dietary diversity declined significantly at five-year follow-up, while those with low baseline scores remained stable or improved [34]. Importantly, the intervention effect in our study was independent of baseline dietary diversity, and the RTM pattern did not differ between the intervention and control groups. This strongly suggests that the program's impact is genuine and not an artefact of statistical regression. These findings highlight the importance of accounting for RTM in intervention research to avoid misinterpreting natural fluctuations as program effects.

The substantial decline in adequate dietary diversity in the control group (from 27.0% to 6.9%) is notable and likely reflects the seasonal food scarcity characteristic of the 'lean season' in rural Ethiopia [35]. The study period (March to June) encompasses a transition in the agricultural cycle from the post-harvest period to the pre-harvest 'hunger gap' when household food stores are depleted, and fresh produce is scarce. This seasonal pattern, driven by the interplay of agricultural production, market supply, and household economics, is a well-documented challenge in the region [35] and underscores the importance of seasonality in dietary assessments. The intervention group's ability to maintain and even improve dietary diversity during this period suggests the education may have helped women better use available resources, including stored foods, fishing, and livestock products, thereby protecting them from the typical seasonal decline.

Regarding the theoretical mechanisms of behaviour change, the intervention demonstrated significant improvements in most HBM constructs at endline compared to

the control group. Self-efficacy was the strongest mediator of the intervention effect on dietary diversity practices. Perceived benefits and perceived barriers were also significant mediators. The significant improvement in perceived benefits indicates that women recognized the tangible advantages of diverse diets for fetal and maternal health, reinforcing their motivation to adopt the recommended practices. Perceived susceptibility demonstrated a statistically significant but relatively minor mediating role, suggesting that while the intervention may have increased women's awareness of their personal risk, this awareness alone was not the primary driver of behavioral change. In contrast, perceived severity and cues to action did not emerge as significant mediators.

These findings are consistent with prior HBM-based interventions in Ethiopia and elsewhere [9] and confirm that the educational content effectively modified both the cognitive appraisals of undernutrition risk and the practical facilitators of dietary behavior. The significant reduction in perceived barriers, particularly around cost, availability, and household food allocation, is conceptually central to the HBM and suggests that the intervention successfully translated abstract nutritional knowledge into actionable, context-specific solutions (e.g., identifying affordable local nutrient-dense foods, meal planning, and negotiating household food sharing). The substantial increases in women's self-efficacy (confidence) to improve dietary intake further support this interpretation; the between-group difference in self-efficacy was +1.49 points, with within-group changes of +2.40 in the intervention group versus +1.14 in controls, underscoring the intervention's impact.

Similar studies demonstrated significant improvements in HBM constructs. A quasi-experimental study on cardiovascular disease risk factors in Shiraz, Iran, significantly improved most HBM constructs, with effect sizes of +0.130 to +0.312 [36], showcasing the

model's validity in shaping health behaviours across different contexts, as observed in the complex dietary and behavioral modifications in this study. An intervention targeting violence-preventive behaviours among (rural) older women showed significant improvements in nutrition knowledge, attitude, and all HBM constructs [37]. These studies, alongside the current findings, reinforce the HBM's theoretical validity and practical utility in health promotion programmes across diverse health contexts.

This study has several notable strengths, including a cluster-randomized controlled trial design, a high retention rate (97.9%), comprehensive fidelity monitoring, rigorous statistical analysis using GEE with a Negative Binomial Distribution, and thorough instrument validation. Grounded in the Health Belief Model, the intervention enabled examination of theoretical mechanisms and was equally effective across all socioeconomic subgroups, supporting its equity-focused applicability. The marginal association between family size and dietary diversity ($p = 0.050$) warrants cautious interpretation; larger households may face greater food allocation challenges, though the intervention effect remained robust and consistent across all household sizes. However, some limitations must be acknowledged. Dietary diversity was assessed using a self-reported 24-hour recall, which is susceptible to recall and social desirability bias. The study was conducted in a single rural zone, limiting generalizability, and the short follow-up period precludes assessment of long-term sustainability. Seasonality was not objectively measured, and no biological markers were collected to validate dietary improvements. The intervention's resource-intensive nature raises questions about cost-effectiveness and scalability.

Clinical and Public Health Implications

This study's findings have important implications for maternal and child nutrition in Ethiopia and similar settings. Primarily, the marked increase in adequate dietary diversity prevalence within the intervention arm supports the idea that intensive nutrition education can elicit substantial behavioral improvements without requiring major economic investments, instead optimizing the use of existing household food resources. Moreover, the synergistic effectiveness of the dual-delivery model comprising group-based sessions for scalable knowledge transfer and peer reinforcement, coupled with individual home visits for personalized counseling and contextual barrier mitigation, supports its pragmatic feasibility for broader regional scale-up. Critically, the absence of significant covariate interactions confirms the intervention's uniform efficacy across all socioeconomic and demographic strata, thereby precluding the exacerbation of existing disparities and underscoring its strategic salience for equity-oriented nutrition programming.

Conclusions

An HBM-based nutrition education intervention significantly improved dietary diversity among pregnant women in rural western Ethiopia and demonstrated a protective effect against seasonal dietary decline. The intervention worked through multiple HBM pathways, most notably by reducing perceived barriers and enhancing self-efficacy. The magnitude of improvement observed (a mean increase of 1.05 food groups) carries important clinical implications, with the potential to reduce adverse pregnancy outcomes. The intervention's compatibility with Ethiopia's existing Health Extension Program infrastructure suggests strong potential for sustainable integration into routine antenatal care, though it will require

careful attention to training, supervision, and resource allocation. While this trial did not include male involvement, future adaptations could explore its potential benefits. These findings provide evidence that behaviourally informed nutrition education can enhance maternal dietary practices in resource-limited settings. However, further implementation research is warranted to evaluate the long-term sustainability, scalability, feasibility, and cost-effectiveness of integrating HBM-based nutrition education into routine antenatal care services.

Data Sharing

Data are available on reasonable request from the corresponding author.

Conflict of Interest

The authors declare no competing interests.

Ethical Approval and Consent

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki [38] and the Ethiopian National Research Ethics Review Guidelines of 2014 [39]. The Institutional Review Board of the Gambella Peoples National Regional State Health Bureau granted ethical approval. Permission was secured from the Nuer Zone Health Office and district health authorities. All participants received detailed information about the study objectives, procedures, potential risks, and benefits, and provided written informed consent before enrollment. For those who could not read and write, an impartial witness was present during the consent process. Participants were assured that their participation was voluntary and that they could withdraw at any time without affecting

their healthcare. We anonymised data using unique identification codes, and stored all information securely on password-protected computers. Pregnant women identified with undernutrition (MUAC < 23 cm) or other health conditions were referred to the nearest health facility for appropriate care. To ensure beneficence, the control group received the educational materials and a condensed version of the intervention after endline data collection. Findings will be disseminated to the community, district health authorities, and the regional health bureau to inform policy and practice.

Authors' Contribution

The corresponding author contributed to all phases of the research project, from Conception and Design, Execution (Data Acquisition), Data Analysis and Interpretation, and Manuscript Preparation (Drafting and Finalization), while the other authors contributed to Conception and Design, Interpretation, and Manuscript Revision and agreed to publication in this journal.

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