Beressa et al. BMC Pregnancy and Childbirth (2025) 25:196
https://doi.org/10.1186/s12884-025-07284-x

BMC Pregnancy and Childbirth

RESEARCH

Open Access

Effect of nutrition education integrating the health belief model and theory of planned behavior during pregnancy on gestational weight gain and birth weight in Southeast Ethiopia using complex analyses

Girma Beressa[1,3*], Susan J. Whiting[2] and Tefera Belachew[3]

Abstract

Background The incidence of inadequate or excessive gestational weight gain (GWG) is an indicator of reproductive health problems. However, scientific evidence for the effect of nutrition education during pregnancy on GWG and neonatal birth weight (BW) in urban settings in Ethiopia is sparse. This study aimed to assess the effect of nutrition education during pregnancy on GWG and neonatal birth weight (BW) in urban settings in Southeast Ethiopia.

Methods A community-based two-arm parallel cluster randomized controlled trial was conducted among 447 randomly selected pregnant women attending antenatal care (224 intervention and 223 control) from February to December 2021. Study participants were selected by multistage cluster sampling followed by systematic sampling. Women receiving the intervention received six nutrition education sessions, while women in the control group received standard care. GWG was the difference between the last recorded weight before delivery and the weight recorded during the first trimester. BW was measured within the first hour of delivery. The generalized structural equations model (GSEM) and structural equations model (SEM) were used to examine the direct, indirect, and total effects of nutrition education on GWG and BW via the dietary diversity score (DDS), food security (FS), and knowledge.

Results The GSEM revealed that receiving intervention during pregnancy had a total effect on GWG [(AOR = 2.056, 95% CI: 1.705, 2.695)]. Having dietary diversity had direct and total effects on GWG [(AOR = 1.105, 95% CI: 1.022, 1.196)]. Having food security had a total effect on GWG [(AOR = 1.928, 95% CI: 1.817, 2.052)]. Having fruit and vegetable knowledge had a total effect on GWG [(AOR = 1.971, 95% CI: 1.856, 2.105)]. The SEM revealed that receiving intervention during pregnancy had a direct effect on BW (unstandardized β = 0.144, 95% CI: 0.034, 0.252). Similarly, it revealed that receiving intervention during pregnancy had a direct effect on DDS (β = 0.580, 95% CI: 0.024, 1.038). Likewise, it indicated that receiving intervention during pregnancy had a total effect on increasing BW (β = 0.137, 95% CI: 0.029, 0.243). Nevertheless, there was no statistically observed indirect effect of nutrition education during pregnancy on GWG and BW via mediators.

*Correspondence:
Girma Beressa
gberessa@gmail.com
Full list of author information is available at the end of the article

© The Author(s) 2025. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by-nc-nd/4.0/.

Conclusion The SEM revealed that receiving nutrition education interventions during pregnancy had a total effect on GWG and direct and total effects on BW. The generalized structural equation modelling (GSEM) and structural equation modelling (SEM) findings show that integrating theory-based nutrition education during pregnancy will improve gestational weight gain (GWG) and birth weight (BW) in Ethiopia.

Trial registration The trial was registered on Pan African Clinical Trials Registry (PACTR202201731802989, retrospectively registered on 24/01/ 2022).

Keywords Birth weight, Nutrition education, Pregnancy, Recommended GWG, SEM, Ethiopia

Introduction

The amount of weight gained during pregnancy, from conception till the baby is born, is known as gestational weight gain (GWG). Depending on the woman's pre-pregnancy body mass index (BMI), differing amounts of GWG are recommended. Women with a BMI of less than 18.5 kg/m^2 are advised to gain 12.5–18 kg; women with a BMI of between 18.5 and 24.9 kg/m^2 are advised to gain 11.5–16 kg; women with a BMI of between 25.0 and 29.9 kg/m^2 are advised to gain 7–11.5 kg; and women with a BMI of greater than 30.0 kg/m^2 are advised to gain 5–9 kg [1]. It has been demonstrated that inadequate weight gain or weight gain below the lower cut-offs can negatively affect maternal [2] and birth outcomes [2–4], and inadequate GWG is a significant public health concern in sub-Saharan Africa (SSA) [5–10]. Low birth weight (LBW) and preterm birth (PTB) are more likely to occur in pregnant women who do not gain enough weight [11]. Given the significant incidence of prenatal under-nutrition [12], persistently low GWG remains a burden for the future health of women as well as their offspring, continuing the cross-generational impacts of chronic under-nutrition in early life. In contrast, pregnant women who gain excessive gestational weight are at a higher risk of having gestational hypertension (HTN) and diabetes [13], caesarean birth [14], and significant postpartum weight retention [15].

The World Health Organization (WHO) defines LBW as a birth weight (BW) of less than 2500 g, regardless of gestational age [16]. The BW of a newborn baby is the first weight record, preferably when taken within an hour of birth. BW is a good indicator of multifaceted public health problems, including long-term maternal malnutrition, chronic illness, and poor health care during pregnancy [17]. LBW is estimated to account for 15% to 20% of all births worldwide, and a majority (90%) of them are found in low- and middle-income countries (LMICs) [16]. LBW is still the single most important predictor of infant morbidity and mortality worldwide [18]. The WHO has identified LBW as a public health priority and targeted a 30% reduction in LBW globally between 2012 and 2025 [16]. The proportion of LBW was 13% [17], whereas the pooled prevalence of LBW in Ethiopia was 17.3% [19].

Survivors are more likely to be stunted and have decreased cognitive function [20], which can have a detrimental impact on school performance, job chances, and productivity later in life [21]. Predictors of LBW include maternal and foetal factors, lack of nutrition counselling, not taking an additional meal during pregnancy, not taking an iron supplement, malaria during pregnancy [22–25], and food security [26]. Despite the negative repercussions on GWG, BW, and other delivery outcomes, Ethiopian pregnant women were reported to consume less than the recommended levels of numerous critical nutrients [27, 28].

Nutrition education is critical in nutrition behavior change attempts because it improves participants' nutrition and food literacy [29]. The selection of the proper model or theory is the most crucial stage in recognizing the different elements influencing behavior and in planning and putting educational and intervention programs into action [30]. In this nutrition education, an integrated health belief model (HBM) and the theory of planned behavior (TPB) were employed to increase women's dietary knowledge during pregnancy on dietary diversity, nutritional status, and pregnancy outcomes [31]. Nutrition education is provided in Ethiopia during antenatal care (ANC) visits and at the community level by health professionals and urban health extension workers (UHEWs), with a focus on the need for pregnant women to consume one additional meal from available foods. However, this form of education was ineffective in changing pregnant women's dietary habits [32].

Previous observational studies in Ethiopia recommended increasing nutrition education during pregnancy [8–10], such as counselling on the consumption of nutrient-rich, locally available foods, dietary quality, prenatal care utilization, and food and nutrient supplementation (for example, iron-folic acid (IFAS), calcium, and multiple micronutrients), as well as weight during pregnancy to ensure a healthy weight gain [33, 23, 34] and to reduce the incidence of LBW [35, 36]. Therefore, this study aimed to assess the effect of nutrition education during pregnancy on GWG and newborn birth weight in urban settings in Southeast Ethiopia using complex analyses.

Methods

Study design, setting, and subjects

A community-based, two-arm, parallel cluster randomized controlled trial (cRCT) study using a 1:1 ratio was carried out among pregnant women receiving antenatal care at medical facilities. It took place in Robe and Goba towns, located in Bale Zone, Southeast Ethiopia, from February to December 2021. These towns are located 430 and 444 km (respectively) from Addis Ababa. Details are available elsewhere [37]. In Goba and Robe towns, the corresponding numbers of pregnant women were 1,832 and 2,048, respectively. The source population was all pregnant women in their first and early-second trimesters who attended ANC in the Robe and Goba Towns. The study population included all first- and early-second-trimester pregnant women attending ANC in the selected Robe and Goba towns. All first- and early-second-trimester pregnant women who lived permanently in the study area were included in the study. The study did not include pregnant women who had HTN or diabetes mellitus.

Sample size determination and sampling techniques

By assuming an effect size of 0.25, a 95% confidence level (CI), a precision of 0.05, and a power (1- β) of 80%, the sample size was calculated using G-Power software version 3.1 [38]. The computed sample size was 120. Using the maximum sample size and considering a design effect (DE) of 2 and a 10% attrition rate, the final sample size was 264. Nonetheless, 454 were drawn (intervention group = 227, control group = 227) since the computed sample size for one of the broader study's other objectives was larger [37]. A maximum likelihood (ML) estimate of multivariate normal data based on Monte-Carlo investigations is recommended in SEM with a sample size of 200–400 [39].

Robe and Goba towns were chosen at random. Robe Town has three kebeles, whereas Goba Town has two kebeles. Robe and Goba towns have 36 and 24 clusters, respectively. The number of pregnant women in each cluster was determined using birth data prepared by UHEWs. Clusters were randomly allocated to the intervention and control groups in a 1:1 ratio. Pregnant women in the Robe Town intervention group received the treatment, while those in Goba Town did not. The sample size was allocated to each cluster by probability proportional to size (PPS). Pregnant women were recruited utilizing a systematic sampling technique. If a pregnant woman was not present at her house for the interview, another woman who met the criteria was interviewed with the serial number, and then the following day, the home of the absent woman was revisited. Gestational age was determined by asking about the first day of the last menstrual period (LMP) and confirming pregnancy with a pregnancy test.

Randomization, intervention allocation, and blinding

After the pregnant women were assessed for eligibility, the lead author randomly assigned clusters to the intervention and control groups by tossing coins. During nutrition education, local languages, Afan Oromo or Amharic, were employed as the languages of communication. The intervention group received nutrition education, counselling cards, and a structured work schedule. The HBM and TPB guiding principles were used to develop the lessons' key takeaways. HBM elucidates health and related behaviors, while prediction of intention and behavior was conducted using the TPB constructs [30, 40]. It was adapted on the recommendation of the Ministry of Health (MOH), Ethiopia [41].

Baseline and end-line assessments were made for the two groups. After baseline data collection, pregnant women in the intervention received nutrition education every trimester consistently for six months (six sessions) after they were recruited at their homes in each cluster. Recruitment was done when animal-source foods (ASF) were allowed. Nutrition education was delivered for 30 to 45 min every session by six nurses holding Bachelor of Science (BSc) degrees under the supervision of Master of Public Health (MPH) specialists.

The main topics covered in the session included: increasing knowledge of iron-rich food sources, iron-folate acid supplements (IFAS), iodized salt, meal frequency, and portion size with increasing gestational age; diversifying one's diet; iron absorption enhancers and inhibitors; reducing heavy workloads; taking day rest; physical exercise; increasing utilization of health services; and interrupting the intergenerational life cycle of malnutrition; increasing pregnant women's perceptions of under nutrition and factors leading to it, poor eating practices causing inadequate dietary intake and disease, a food-based strategy, dietary changes, raising awareness of fruit and vegetable (FV) intake through diversification, identifying obstacles and finding solutions to them, lowering the perceived obstacles to creating an FV, enlisting the help of participants in coming up with solutions, The improvement of participants' perceptions of control and intention; specific food taboos (meat and eggs); knowledge and attitudes about pregnant women's capacity to modify feeding practices; the improvement of participants' perceptions of control and intention; and the improvement of participants' hand washing proficiency.

The methods used to give counselling included presentations, discussions, demonstrations, and picture-based exercises. Observation, self-report, and attendance were used to assess compliance. MPH specialists led the counselling session. Critical counselling techniques, important messages, realistic activities, and the GALIDRAA (greet, ask, listen, identify, discuss, recommend, agree, and make a follow-up appointment) processes were applied by the trainers.

The intervention group consistently received dietary education from nurses. Due to the unique characteristics of the cluster RCT and the nature of the intervention under investigation, no allocation concealment was adopted in the trial. Because the two towns were so far apart, the study was not blinded. Pregnant women were made aware of the intervention; however, they were blinded to the research hypothesis. Once the pregnant women were enrolled, reasonable steps were taken to encourage their retention and complete follow-up for the duration of the trial by providing them with bars of soap to reduce missing data. In this way, interest in the study was maintained through regular conversations about compliance with the intervention as well as home visits by trainers. Moreover, home visits were planned to minimize the burden placed on pregnant women by follow-up visits.

There was no set schedule for the control groups that received regular medical care. At the conclusion of the study, the control group received a brief intervention to ensure justice and a high level of post recruitment satisfaction. The MOH's routine health extension programme packages in Ethiopia include 16 components: family health (family planning, maternal and child health, nutrition, and vaccination services); disease prevention and control (HIV/AIDS and STIs; tuberculosis; malaria; and first aid care); hygiene and sanitation (promotion of sanitary latrines; waste disposal management; water supply; food hygiene and safety; control of insects and rodents; personal hygiene); and health education) [42].

Data collection

An interviewer-administered, structured questionnaire was used to collect data. The data collection instruments were adapted from the Ethiopian Demographic and Health Survey (EDHS) and existing studies [10, 17, 34, 43–45]. Prior to the intervention, data on sociodemographic and economic aspects, substance abuse (alcohol, smoking, tea, or coffee), and reproductive history were obtained. Nutritional, health care delivery system, intimate partner violence (IPV), physical exercise, knowledge, practice, HBM, and TPB instruments were collected before and after the intervention.

A 24-h qualitative dietary recall was used to compute the dietary diversity score (DDS). The DDS for women is a nine-food group score that is indicated as a qualitative indicator of micronutrient sufficiency in a diet [46]. The score was calculated using nine food groups to represent the micronutrient sufficiency of the diet. Participants were asked to recall everything they had eaten and consumed in the previous 24 h, both in and out of their residences. End-line data were collected after 36 weeks. In addition, participants were asked to recall any snacks they had eaten in between large meals. Consumption of a food item during the reference period received a score of "1," but nonconsumption received a score of "0." The foods were then divided into nine categories: (3) vitamin-A-rich fruits and vegetables; (4) other fruits and vegetables; (5) beans, nuts, and seeds; (6) meat and fish; (7) fats and oils; (8) milk and milk products; and (9) eggs. DDS was computed by summing the food groups consumed during the reference period and categorizing them into tertiles, with the highest tertile representing high DDS and the two lower tertiles representing low DDS [47].

Because mid-upper arm circumference (MUAC) changes minimally during pregnancy, it is considered a better indicator of pregnant women's nutritional status than body mass index (BMI), as pregnancy-related weight gain affects the reliability of using BMI to assess the nutritional status of pregnant women. MUAC measures were taken on patients' left arms to the nearest 0.1 cm using flexible and nonstretchable measuring tapes, as per standard methods [48]. Taking this into account, MUAC was employed in this study to determine the nutritional status of the women [48, 49]. Pregnant women with MUAC $\geq$ 23 cm were regarded as well-nourished, while those with MUAC $<$ 23 cm were classified as undernourished [48, 50].

The Hemo-Cue1 Hb 301 system (HemoCue AB, Angelholm, Sweden) was used at each study setting by skilled medical laboratory technologists to measure the hemoglobin (Hgb) concentration (in g/dL) of pregnant women. Five milliliters of venous blood was taken and centrifuged for 5 min in a microhematocrit tube with an anticoagulant. Details are available elsewhere [51]. Household income was classified into tertiles: "high," "medium," and "poor" [52]. Finally, the highest tertile was labelled having a high income, while the two lowest tertiles were labelled having a low income. The wealth index was calculated using principal component analysis (PCA) and household asset items, among other characteristics. It was used to rank and order respondents' economic status into tertiles of rich, medium, and low. Finally, the highest tertile was coded as having a more wealthy lifestyle, while the two lowest tertiles were coded as having a less wealthy lifestyle. Its details are available elsewhere [37]. The status of food security was assessed using 27 previously verified questions. Food-secure, slightly, moderately, and severely food-insecure families were characterized as having less than the first two, two to 10, eleven to seventeen, and more than seventeen food insecurity indicators, respectively [53].

Each HBM was determined using the sums of a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree) to form a composite question: perceived susceptibility (3 items), perceived severity, and perceived benefits (4 items each), perceived barriers (5 items), cues to action, and self-efficacy (4 items each) [40] and TPB questions: attitude and subjective norms (3 items each), perceived behavioral control (2 items), and behavioral intention (7 items) [31]. The factor scores were summed and ranked into tertiles, and the highest tertile was labelled as having "yes" for perceived susceptibility, severity, benefit, barriers, cues to action, self-efficacy, positive attitude, subjective norm, perceived behavioral control, and behavioral intention; otherwise, the two lower tertiles were labelled as "no."

To assess the relevance of fruits and vegetables, a ten-item knowledge test was also used [54]. A respondent was given a score of "1" if they replied correctly; otherwise, rated "0". The scores were then computed and ranked by tertile, with the highest tertile labelled as having the highest degree of nutrition knowledge. To lower the risk of low birth weight, maternal anaemia, and iron deficiency, pregnant women should take daily oral iron and folate supplements for 180 days as part of their prenatal care plan [55].

Data quality control

To guarantee the consistency of the data, the questionnaire was designed in English and then translated into the local languages, "Afan Oromo" and "Amharic," and back-translated into English by independent language professionals. The questionnaire was also pretested on 5% of the total predicted sample size, which had similar characteristics to the research population in a different neighboring context. An epidemiologist and a biostatistician reviewed the completed questionnaire to ensure its face and content validity. Finally, the items were revised based on the findings of the pretest and specialty views. Training was given to eight nurses with BSc degrees as data collectors and four MPH specialists as supervisors on the objectives of the study, data collection instruments, and ethical issues to minimize interviewers' bias. Six counsellors were trained by the lead author. The lead author met with counsellors every two weeks to discuss ways of improving the counselling process. Data supervisors rigorously supervised the data collectors on a daily basis to ensure that the questionnaire was completed successfully and took appropriate action if it was not. To increase response rates, respondents were interviewed at their homes. Cronbach's alpha was also utilized to assess the internal consistency of the tools' cognitive, affective, and psychomotor domains (Supplemental Table 1).

Outcome assessment

The DDS was the primary outcome variable, and the results of finding an improvement in the DDS were previously published [37]. GWG and birth weight were secondary outcomes. The difference between the last recorded weight (just before delivery) and the initial recorded weight during the first- and early-second-trimesters was used to compute the total GWG. Participants' initial measured weight (before or at 16 weeks' gestation) is used as a proxy for their weight at conception [1]. The weight of the newborns was measured in kg within the first hour of birth using a calibrated Seca scale and rounded to the nearest 100 g [44, 56]. Birth weight (BW) was gathered from the health facilities where each woman had her baby. The health facilities where the mothers gave birth were traced through cell phone conversations with the mothers. Before each measurement, the scales were calibrated with a known-weight object. Furthermore, before weighing each newborn, the reading on each scale was reset to zero.

Data processing, model building, and analysis

The data were reviewed for completeness, consistency, and accuracy. The data were then entered, cleaned, and analyzed using STATA™ version 14 and SPSS version 20 software. Descriptive statistics (frequencies, percentages, medians, and interquartile ranges (IQRs)) were generated for the selected variables. The baseline characteristics of the intervention and control groups were compared using the chi-square test. A Mann–Whitney U test was used to compare the continuous outcome variables of interest (GWG and BW) between the intervention and control groups. The highest collinearity among independent variables was 0.12 for GWG. Stata command "vif", was employed to check multicollinearity (variation inflation factor (mean VIF) = 1.06 for BW. We assessed the intra class correlation coefficient (ICC) using the "estat icc" Stata command. The skewness and kurtosis tests were used to assess an assumption of multivariate normality. Accordingly, a maximum likelihood (ML) estimate was employed along with a non-parametric bootstrapping replications (2000) approach to address the violations of multivariate normality [57–59] for BW. The Stata commands 'linktest' and 'ovtest' were used to assess model specification and omitted-variable bias, respectively.

Nutrition knowledge, dietary diversity, and food security are all latent variables that are difficult to properly assess directly. In regard to potential variables, the usual statistical method may not be capable of elucidating complex causal links. Thus, our study attempts to answer the research questions: to what extent does nutrition education in Ethiopia improve GWG and BW via mediators? Generalized structural equation modelling (GSEM) was used to examine the association between exogenous and endogenous or mediating variables. Structural equation modelling (SEM) is a considerably superior multivariate analytic strategy that compensates for the shortcomings of traditional statistical techniques [60]. It is a set of linear simultaneous equations that is an effective statistical tool for examining direct and indirect (i.e., through mediators) correlations between potential and observed variables [61, 62].

We used GSEM and SEM to explicate the direct, indirect, and total effect of nutrition education on GWG and BW via nutrition knowledge, dietary diversity, and food security. GWG was treated as an ordinal family and logit link function. BW was treated as a continuous response variable. SEM employs a hybrid of factor analysis and multiple regression analysis to answer research questions involving complex, multifaceted constructs measured with error, and to characterize systems of interactions with direct and indirect effects [63]. Because it can appropriately accommodate several indicators measuring a latent construct with measurement error, SEM is a viable alternative to multiple regression analyses.

Covariance, which represents the strength of the linear relationship between two variables, is the fundamental datum examined in SEM. The variables observed can be continuous, censored, binary, ordered categorical (ordinal), or combinations of thereof [64]. A direct effect is the cause-and-effect relationship between an independent and a dependent variable. An indirect effect is the causal effect of an independent variable on a dependent variable via a third variable, an endogenous variable known as the mediator. The total effect is the sum of all potential pathways from an independent variable to a dependent variable, including both direct and indirect effects [65]. A mediator is an intervening variable that exists along the causal pathway between the exposure or intervention and the endpoint variable [66].

Adjusted odds ratio (AOR) and path coefficients (unstandardized β) along with a 95% confidence interval (CI) and standard error (SE) were estimated for GWG and BW, respectively. The model's goodness of fit was examined using recommended global goodness of fit indices and cut-offs [63] for BW. Initially, randomly assigned pregnant women were examined in the groups to which they were assigned (intention-to-treat analysis principle). The statistical significance of the association was declared at a p value of less than 0.05, and all tests were two-sided.

Hypothesized path model

Based on the findings of the existing studies, the theoretical relationships, and the authors' experiences, the hypothesized association between manifest and latent variables and the respective endpoint variable was built. Then, viable paths for linking the nutrition education intervention to GWG and BW were constructed (Supplemental Figs. 1 and 2).

Results

Sociodemographic and economic factors

A total of 224 (98.7%) and 223 (98.2%) newborns were included in the analysis in the intervention and control groups, respectively (Fig. 1). There were comparable baseline characteristics between the intervention and control groups (P-value > 0.05). There were 117 (50.2%) males and 106 (49.5%) female newborns in the control groups and 116 (49.8%) males and 108 (50.5%) female newborns in the intervention groups (Table 1).

Health belief model and the theory of planned behavior scores

There was significant improvement in the score of HBM and TPB constructs except for perceived benefit and cues to actions among the intervention group before and after the intervention (P-value < 0.0001). Furthermore, with the exception of perceived severity and cues to action, there was a significant difference in the dimensions of HBM and TPB in the endline data (Table 2).

HBM Health belief model, *TPB* Theory of planned behavior, *P* *P*-value, *SD* Standard deviation.

Effect of nutrition education during pregnancy on gestational weight gain

The median gestational weight gain (GWG) was 10.5 kg and 11 kg in the control group and intervention group, respectively, with IQRs of 2.55 kg. There was not a statistically significant difference in GWG between the control groups and the intervention groups (P = 0.25).

The proportion of types of GWG in the control group was 65.9% (95% CI: (59.9, 72.1%) inadequate gestational weight, 30.5% (95% CI: (24.3, 36.4%) adequate gestational weight, and 3.6% (95% CI: (1.3, 6.3%) excessive gestational weight, whereas in the intervention group it was 63.4% (57.1, 69.9%) inadequate gestational weight, 34.4% (95% CI: (28.2, 40.4%) adequate gestational weight, and 2.2% (95% CI: (0.4, 4.4%) excessive gestational weight.

The final model contained the measurement of the relationship between latent variables and their indicators or

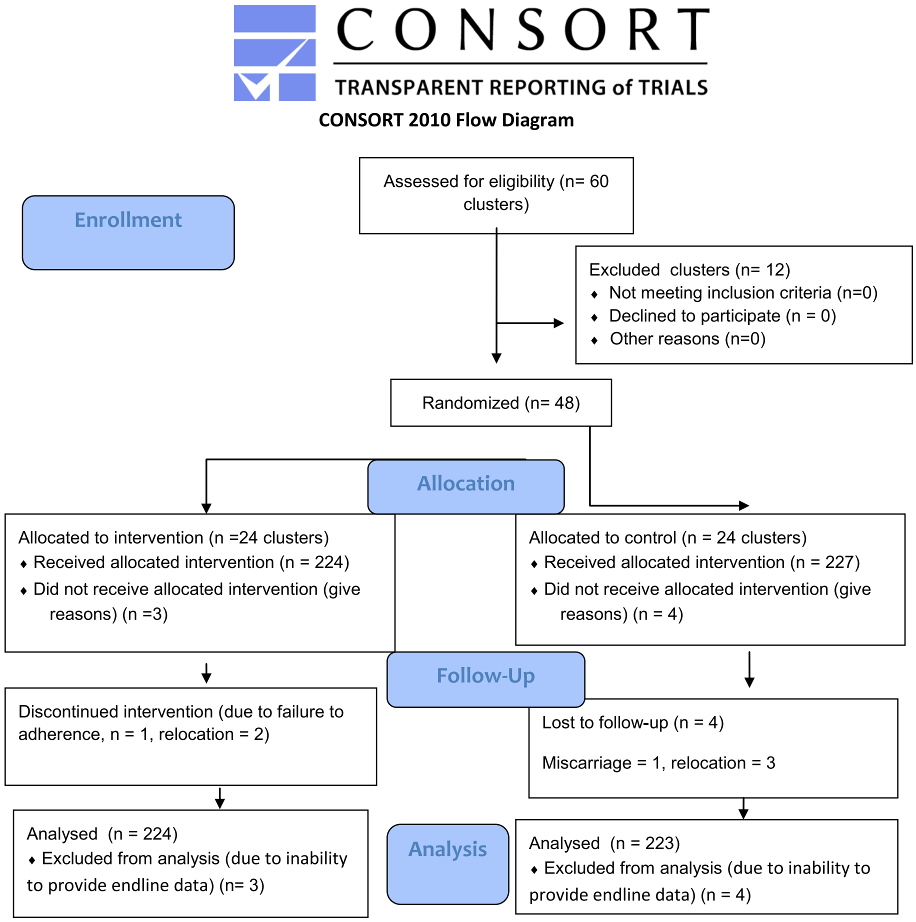

Fig. 1 A CONSORT flow diagram of study subjects

items and structural model components (the relationship between latent variables) (Figs. 2 and 3).

The GSEM revealed that receiving intervention during pregnancy had a total effect on GWG [(AOR = 2.056, 95% CI: 1.705, 2.695)]. Having dietary diversity had direct and total effects on GWG [(AOR = 1.105, 95% CI: 1.022, 1.196)]. Having food security (FS) had a total effect on GWG [(AOR = 1.928, 95% CI: 1.817, 2.052)]. Having fruit and vegetable knowledge had a total effect on GWG [(AOR = 1.971, 95% CI: 1.856, 2.105)]. Similarly, it found that receiving intervention during pregnancy had direct [(β = 1.786, 95% CI: 1.126, 2.834)] and total effects [(β = 2.785, 95% CI: 2.117, 3.842)] on DDS. Having fruit and vegetable knowledge had a direct [(AOR = 1.027, 1.101, 1.178)] and total effect [(AOR = 2.008, 95% CI: 2.074, 2.184)] on DDS. Likewise, having received intervention during pregnancy had a total effect [(AOR = 2.387, 95% CI: 1.969, 2.959)] on FS. Moreover, having fruit and vegetable knowledge had direct and total effects on FS [(AOR = 0.903, 95% CI: 0.819, 0.995)]. Nevertheless, there was no statistically observed indirect effect of nutrition education during pregnancy on GWG via mediators (Table 3).

Effect of nutrition education during pregnancy on birth weight

The median birth weight (BW) was 3.05 kg with an inter quartile range (IQR) of 2.55 kg and 3.60 kg in the control group, whereas it was 3.30 kg with an IQR of 2.7 kg and 3.69 kg in the intervention group. This was a statistically significant difference between the control groups and the intervention groups (P = 0.03).

The SEM revealed that receiving intervention during pregnancy had a direct effect on BW (unstandardized β = 0.144, 95% CI: (0.034, 0.252). Similarly, it revealed that receiving intervention during pregnancy had direct effect on DDS (β = 0.580, 95% CI: 0.024, 1.038). Likewise, it indicated that receiving intervention during pregnancy had a total effect on increasing BW (β = 0.137, 95% CI: 0.029, 0.243). Nevertheless, there was no statistically observed indirect effect of nutrition education during pregnancy on BW via mediators (Table 4).

Table 1 Baseline socio-demographic and economic characteristics of pregnant women in Southeast Ethiopia, 2020/21

Variables	Control group (*n* = 223) Frequency (%)	Intervention group (*n* = 224) Frequency (%)	*P*-value
Age (years)			
< 20	27 (12.1)	22 (9.8)	0.44
≥20	196 (87.9)	202 (90.2)	
Marital status			
Married	222 (99.55)	223 (99.55)	0.99
Unmarried	1 (0.45)	1 (0.45)	
Religion			
Orthodox	112 (50.22)	101 (45.09)	0.58
Muslim	88 (39.46)	102 (45.54)	
Protestant	21 (9.42)	20 (8.93)	
Others[a]	2 (0.90)	1 (0.45)	
Ethnicity			
Oromo	187 (83.86)	193 (86.16)	**0.03**
Amhara	33 (14.80)	21 (9.38)	
Others ◱	3 (1.35)	10 (4.46)	
Occupation status			
Housewife	139 (62.33)	124 (55.36)	0.14
Government employee	46 (20.63)	52 (23.21)	
NGO employee	3 (1.35)	13 (5.80)	
Petty trade	22 (9.87)	22 (9.82)	
Student	9 (4.04)	11 (4.91)	
Daily laborer	4 (1.79)	2 (0.89)	
Maternal education			
Literate	209 (93.72)	212 (94.64)	0.68
Illiterate	14 (6.28)	12 (5.36)	
Spouse education			
No formal education	31 (13.90)	24 (10.71)	0.20
Primary education	52 (23.32)	39 (17.41)	
Secondary education	66 (29.60)	82 (36.61)	
Tertiary education	74 (33.18)	79 (35.27)	
Wealth index			
High	66 (29.60)	76 (33.93)	0.33
Low	157 (70.40)	148 (66.07)	
Family size			
< 5	197 (88.34)	188 (83.93)	0.18
≥5	26 (11.66)	36 (16.07)	
Food security			
Food insecure	89 (39.91)	82 (36.61)	0.47
Food secured	134 (60.09)	142 (63.39)	

[a] Others: ◱Wakafeta; Others: Gurage, Hadiya; NGO: Non-governmental organization

Reference category: Dietary diversity score (DDS) (cont.); control, FS: food insecure; hemoglobin (Hgb) (cont.), mid-upper arm circumference (MUAC) (cont.), gestational weight gain (GWG) (cont.), gestational age (cont.), knowledge (cont.), food secure (cont.), BW: birth weight; β: beta coefficient; SE: standard error; P: P-value; CI: confidence interval; EL: end-line; Cont.: continuous.

Goodness-of-fit model test

The results of the goodness of fit (GFI) model test were as follows: the likelihood ratio (P value > 0.188; X^2/df < 5); the root mean squared error of approximation (RMSEA) is 0.028 (90% CI: 0.001, 0.059); Pclose is 0.86; the comparative fit index (CFI) is 0.790; the Tucker-Lewis index is 0.546; and the standardized root mean square residual (SRMR) is 0.025 for BW.

Table 2 Comparison of the health belief model and the theory of planned behavior constructs between and within the intervention and control groups during pregnancy in Southeast Ethiopia, 2021

HBM and TPB constructs	Study period	HBM and TPB constructs score		P
		Control group, Mean ± SD	Intervention group, Mean ± SD	
Perceived susceptibility	Baseline	5.27 ± 2.2	5.33 ± 2.48	0.80
	Endline	5.46 ± 1.95	7.43 ± 1.74	< 0.0001
	P	0.04	< 0.0001	
Perceived severity	Baseline	8.05 ± 2.70)	7.34 ± 2.72	0.006
	Endline	8.57 ± 2.49)	8.30 ± 2.36	0.25
	P	< 0.0001	< 0.0001	
Perceived Benefit	Baseline	11.04 ± 1.66	11.46 ± 1.42	0.004
	Endline	10.86 ± 1.79	11.57 ± 1.22	< 0.0001
	P	0.10	0.07	
Perceived barriers	Baseline	8.55 ± 2.71	8.20 ± 2.43	0.39
	Endline	9.25 ± 2.88	7.88 ± 2.54	< 0.0001
	P	< 0.0001	0.02	
Cues to action	Baseline	11.0 ± 2.61	11.65 ± 1.15	< 0.0001
	Endline	11.61 ± 1.44	11.55 ± 1.19	0.57
	P	< 0.0001	0.25	
Self-efficacy	Baseline	9.22 ± 2.07	9.93 ± 2.28	0.001
	Endline	9.55 ± 11.81	10.58 ± 1.69	< 0.0001
	P	< 0.0001	< 0.0001	
Attitude	Baseline	13.32 ± 1.66	12.32 ± 3.84	< 0.0001
	Endline	13.61 ± 1.69	14.23 ± 1.49	< 0.0001
	P	0.002	< 0.0001	
Subjective norm	Baseline	13.46 ± 1.55	12.89 ± 3.71	0.04
	Endline	13.80 ± 1.39	14.29 ± 1.51	< 0.0001
	P	< 0.0001	< 0.0001	
Perceived behavioral control	Baseline	7.48 ± 2.25	7.92 ± 2.44	0.04
	Endline	8.17 ± 1.92	9.37 ± 1.40	< 0.0001
	P	< 0.0001	< 0.0001	
Behavioral intention	Baseline	31.62 ± 3.52	30.30 ± 8.07	0.02
	Endline	32.91 ± 2.39	33.64 ± 2.71	0.003
	P	< 0.0001	< 0.0001	

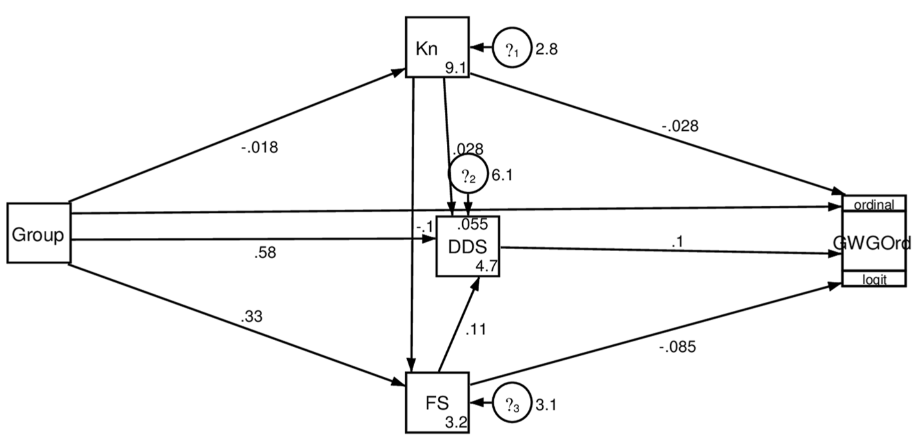

Fig. 2 The GSEM predicted the effect of nutrition education during pregnancy on gestational weight gain

Discussion

This study aimed to elucidate the effect of a nutrition education intervention during pregnancy on gestational weight gain (GWG) and birth weight (BW) in urban areas in Southeast Ethiopia using a structural equation modelling (SEM) approach. The proportion of inadequate

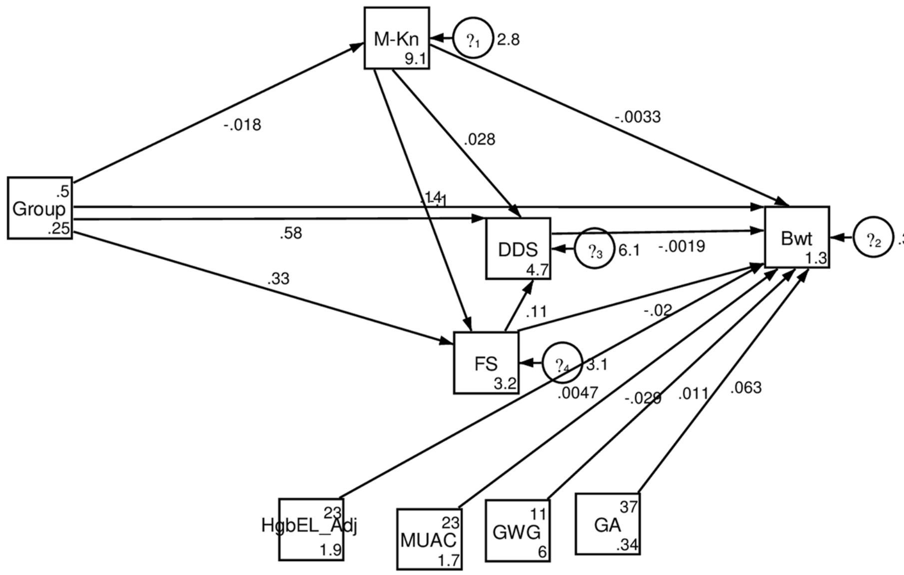

Fig. 3 The SEM predicted the effect of nutrition education during pregnancy on birth weight

Table 3 Structural equation modelling predicted the direct, indirect, and total effects of nutrition education during pregnancy on gestational weight gain through mediators, 2021 (*N* = 447)

Gestational weight gain (GWG)	Direct effect (unstandardized factor loading)		Indirect effect (unstandardized factor loading)		Total effect (unstandardized factor loading)	
Variables	**AOR**	**95% CI**	**AOR**	**95% CI**	**AOR**	**95% CI**
Intervention → GWG	1.056	0.712,1.565	1.060	0.993, 1.130	2.056	**1.705, 2.695***
DDS EL	1.105	**1.022, 1.196***	no path		1.105	**1.022, 1.196***
Food secured EL	0.918	0.821, 1.026	1.010	0.996, 1.026	1.928	**1.817, 2.052***
Knowledge EL	0.972	0.867, 1.089	1.003	0.989, 1.016	1.971	**1.856, 2.105***
Intervention → DDS	1.786	**1.126, 2.834***	0.999	0.991, 1.008	2.785	**2.117, 3.842***
Food secure	1.111	0.977, 1.266	0	no path	1.111	0.977, 1.266
Knowledge EL	1.027	**1.101, 1.178***	0.981	0.973, 1.006	2.008	**2.074, 2.184***
Intervention → FS EL	1.386	0.999, 1.925	1.001	0.970, 1.034	2.387	**1.969, 2.959***
Knowledge	0.903	**0.819, 0.995***	0	no path	0.903	**0.819, 0.995***
Intervention → knowledge EL	0.982	0.719, 1.340	0	no path	0.982	0.719, 1.340

*Statistically significant; reference category: control, knowledge EL (cont.), DDS EL (cont.), food-secure EL (cont.): DDS: Dietary diversity score; EL: end-line; SE: standard error; CI: confidence interval; cont.: continuous

GWG was 63.4% in the intervention group compared to the control group. Other studies conducted in Ethiopia [8, 9] showed an even greater degree of inadequate GWG. A meta-analysis [5] of studies from sub-Saharan Africa showed a disparities, with studies involving underweight women having inadequate GWG ranging from 67 to 98%. Another meta-analyses reported lower proportions of inadequate GWG [5, 67]. The proportion of adequate GWG was 34.4%, which was comparable to the meta-analysis conducted in SSA [5].

Finally, the proportion of excessive GWG in our study, around 3% was much lower than in a meta-analysis carried out in LMICs [67]. The findings were also lower than the IOM recommendation [1]. Overall, the results suggest that Ethiopian women come into pregnancy underweight and, during pregnancy, do not receive adequate dietary diversity.

The findings indicated that pregnant women in the intervention group were 2.056 kg more likely to be in GWG in the higher groups. This study's findings are in

Table 4 Structural equation modelling predicted the direct, indirect, and total effects of nutrition education during pregnancy on a newborn's birth weight (BW) via mediators, 2021 (N = 447)

Birth weight (BW)	**Direct effect (unstandardized factor loading)**		**Indirect effect (unstandardized factor loading)**		**Total effect (unstandardized factor loading)**	
Variables	**β (SE)**	**95% CI**	**β (SE)**	**95% CI**	**β (SE)**	**95% CI**
Intervention → BW	0.144 (0.054)	**0.034, 0.252***	−0.008 (0.008)	−0.024, 0.008	0.137 (0.054)	**0.029, 0.243***
DDS EL	−0.001 (0.011)	−0.023, 0.019	0 (no path)	-	−0.001 (0.011)	−0.023, 0.010
FS	−0.020(0.015)	−0.049, 0.010	−0.001(0.001)	−0.001, 0.001	−0.020 (0.015)	−0.049, 0.010
Hgb EL	0.004 (0.019)	−0.034, 0.043	0 (no path)		0.004 (0.019)	−0.034, 0.043
MUAC EL	−0.029 (0.020)	−0.069, 0.001	0 (no path)		−0.029(0.020)	−0.069, 0.011
GWG	0.011 (0.011)	−0.010, 0.031	0 (no path)		0.011 (0.011)	−0.010, 0.031
Gestational age	0.063 (0.046)	−0.028, 0.154	0 (no path)		0.063 (0.046)	−0.028, 0.154
Knowledge EL	−0.003 (0.014)	−0.031, 0.024	0 0.002(0.001)	−0.001, 0.004	0.001 (0.014)	−0.029, 0.026
Intervention → DDS	0.580 (0.233)	**0.024, 1.038***	0.035 (0.029)	−0.023, 0.092	0.615 (0.233)	**0.158, 1.073***
FS → DDS	0.106 (0.064)	−0.019, 0.232	0 (no path)		0.106 (0.064)	−0.019, 0.232
Knowledge EL	0.028(0.070)	−0.109, 0.165	−0.011(0.007)	−0.024, 0.002	0.016 (0.070)	−0.121, 0.153
Intervention → knowledge EL	−0.018 (0.160)	−0.333, 0.295	0 (no path)		−0.018 (0.160)	−0.333, 0.295
Intervention → FS	0.327 (0.167)	−0.001, 0.655	0.001 (0.016)	−0.030, 0.034	0.329 (0.169)	−0.001, 0.660
Knowledge EL	−0.102 (0.063)	−0.228, 0.022	0 (no path)		−0.102 (0.063)	−0.228, 0.022

agreement with studies conducted in Ethiopia [43, 68], Egypt [69], LMICs [70], Iran [71], Bangladesh [72, 73], and Turkey [74]. This could possibly be because pregnant women in the intervention group became more aware of the relevance of dietary intake during pregnancy and GWG using HBM and TPB. This, in turn, increases the women's understanding of the implications of poor diet, the advantages of a balanced diet, food preparation, and weight gain [75].

This might also be due to the fact that nutrition education delivered during pregnancy increases nutrition knowledge of pregnant women, which in turn improves nutrition literacy and understanding during pregnancy [76], as well as the effect of counseling on improving dietary practices [77]. This approach also agreed with the data that interventions are more effective when they try to improve actual conduct or actions crucial for behavior change rather than simply transmitting knowledge [78]. Although lifestyle treatments reduced overall GWG, they were insufficient to provide weight gain within the range recommended by IOM guidelines [79]. However, recent research that examined the effect of lifestyle treatments on GWG found that lifestyle interventions are ineffective or have a low effect on overall GWG [80].

Monitoring GWG is a key step in dealing with inappropriate GWG and reducing its negative outcomes [81]. Food consumption is crucial for adequate GWG. It was evident that the lifestyle intervention was effective in improving food behaviors, increasing physical activity, and lowering excessive GWG [82]. Nutritional behavioral control, according to TPB, is attainable when women have adequate nutrition skills. Cooking demonstrations improved nutrition skills, which improved perceptions of nutrition behavior control [83]. There was no statistically observed indirect effect of nutrition education during pregnancy on GWG via mediators.

The study's findings revealed that receiving intervention during pregnancy had the direct effect of improving BW by 0.144 kg. This agreed with studies conducted in Ethiopia [43, 84], Rwanda [85], Kenya [36], Bangladesh [72, 73, 86], and LMICs [76]. It has also been observed that interactions with a variety of multisectoral intercessions throughout pregnancy may result in a higher BW [87, 88]. Overall, the combined intervention may improve access to and use of various health services, increase household food security, improve maternal nutrition knowledge and safe food preparation, improve access to clean water and sanitation, empower women, and enhance behavior change towards healthy practices. All of these factors could be plausible explanations for the combined intervention's direct effect on BW improvement [87, 88]. The variation could be due to differences in nutrition education, as our study was based on the integration of the HBM and TPB, which improve the retention of new information in pregnant women. These findings show that a sufficient level of nutrition literacy is essential to improve responsiveness to health advice [29]. This might also be due to the difference in understanding among pregnant women about the importance of nutrition during pregnancy as a result of the effect of nutrition education on improving BW. Pregnant women in the intervention group received counselling based on key messages and a client-centered approach. In addition, it may increase health-seeking behavior, women's knowledge [75, 89], and healthy behavior may lead to an improvement in BW [36]. Another factor that had a small but significant effect on decreasing BW was food insecurity (data not shown), which is in agreement with XYZ.

There was no statistically observed indirect effect of nutrition education during pregnancy on BW through DDS, food security, and knowledge. This study's result disagreed with other studies conducted in Ethiopia [43, 84]. It might be that, as perinatal depression was not assessed, the data set did not include those important components.

Moreover, maternal nutrition education and counselling have been shown to dramatically improve dietary behavior among women [77, 89]. The risk factors for LBW increase in women with a low monthly family income. This study's findings agreed with studies carried out in Ethiopia [90–92]. Nutrition education increases income-generating activities such as home gardening, which improves BW. Economic empowerment combined with nutrition education may help women use and readjust their resources to consume an appropriate and high-quality diet, which increases GWG and foetal growth [70]. It is advised to apply health education and health promotion models to obtain meaningful and successful outcomes since they are helpful resources for studying the variables influencing behavior, planning, and effective interventions [93]. The TPB is one of the best theories for successfully changing unhealthy behavior into healthy behaviour [30].

The main strength of this study was that it was a community-based, cluster-randomized, controlled trial (cRCT) in which encouraging the consumption of fruits and vegetables (FV) was integrated with the HBM and TPB, both of which are applicable to relevant and conventional ANC. A cRCT requires both internal and external validity to be generalizable [94]. The cluster character of the study was taken into consideration during the selection of the sample size. Evaluation of program execution and adoption, or the degree to which the setting is representative of the general population, could similarly be used to measure external validity [94].

Moreover, to the best of the authors' knowledge, the current study is the first to adopt the SEM approach, a robust multivariate statistical analysis, to examine the effect of prenatal nutrition education on GWG and BW via mediators in urban settings in Southeast Ethiopia. One advantage of using SEM is that it focuses on latent components rather than the variables used to quantify them. In contrast to earlier research, DDS, food security, and knowledge were considered as latent variables rather than their components as distinct variables. Furthermore, the sample size for this study was large. Hemoglobin values were adjusted for altitude.

There were, however, limitations to the study. Even well-behaved random errors might skew the coefficient estimates of not only BW but also the other control variables included in the analysis. This occurs even when the control variables are error-free [95]. As a result, we employed GSEM and SEM to decrease measurement error. Nonetheless, GSEM did not yield goodness-of-fit values. Moreover, recall bias and social desirability bias could have influenced the findings of our study. Despite this, efforts were made to probe pregnant women numerous times over the course of 24 h to improve dietary recall. Self-reporting, on the other hand, is frequently used in nutrition assessments and has been shown to have more predictive ability than objective assessments [96]. The pre-pregnancy weight was not measured, and therefore we did not know whether the women were mostly underweight prior to pregnancy. Moreover, misclassification of the mediator is a significant potential source of error that might have an influence on exposure-endpoint variable relationships [97]. The US IOM guideline on GWG might not be applicable for Ethiopian pregnant women as it is the recommendation of high-income countries (HICs). As well, this study's findings may not be generalizable to pregnant women living in rural settings in Southeast Ethiopia, as it was conducted among pregnant women residing in urban areas in Southeast Ethiopia. Furthermore, food taboos, cultural norms, and economic constraints may restrict food choices during pregnancy. Selection bias can occur when the sampling technique does not assure a fair representation of all socioeconomic groups. The use of incentives might be a limitation because incentives were not equally given to controls, and this might influence the intervention group.

Conclusion

Overall, nutrition education integrating the health belief model (HBM) and theory of planned behaviour (TPB), using the generalised structural equation modelling (GSEM) and structural equation modelling (SEM) findings, revealed that nutrition education interventions improved gestational weight gain (GWG) and birth weight (BW). It also emphasizes the importance of utilizing GSEM and SEM to examine the impacts of nutrition education during pregnancy on GWG and BW, which will allow researchers to undertake meta-analysis of interventional studies. This study's findings have implications for public health initiatives in urban settings in Ethiopia, and would be useful for policymakers and program planners at various levels.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12884-025-07284-x.

Supplementary Material 1: Supplemental Table 1.

Supplementary Material 2: Supplemental Fig. 1.

Supplementary Material 3: Supplemental Fig. 2.

Acknowledgements

We would like to express our gratitude to Jimma University and local administrative officials for their support. Our thanks also go to the educators, supervisors, data collectors, and pregnant women for their participation.

Authors' contributions

GB participated in the conceptualization, formal analysis, investigation, methodology, resource acquisition, software, supervision, validation, writing the original draft, and writing a review and substantial editing. SW and TB participated in the conceptualization, formal analysis, investigation, methodology, resource acquisition, software, supervision, validation, substantial review and editing. All authors read and approved the manuscript.

Funding

The authors did not receive specific funding for this study.

Data availability

All relevant data for this work are available upon reasonable request from the corresponding author.

Declarations

Ethics approval and consent to particpate

The current study was ethically approved by Jimma University's Institutional Review Board before it began (Protocol #: IRB000296/2012). The health offices provided an authorization letter. All methods were carried out in compliance with the Helsinki Declaration and good clinical practice [98]**.** Each respondent provided informed written consent. The respondents' privacy was maintained. Throughout the data collecting and administration procedure, confidentiality was preserved. The trial for study was registered at Pan African Clinical Trials Registry (PACTR202201731802989), retrospectively registered on 24/01/2022. The study was reported following the Consolidated Standards of Reporting Trials (CONSORT) 2010 statement (Related manuscript Table 1).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Department of Public Health, School of Health Sciences, Madda Walabu University, Goba, Ethiopia. [2]College of Pharmacy and Nutrition, University of Saskatchewan, Saskatoon, Canada. [3]Nutrition and Dietetics Department, Faculty of Public Health, Jimma University, Jimma, Ethiopia.

Received: 21 December 2023 Accepted: 4 February 2025
Published online: 24 February 2025

References

1. Institute of Medicine, National Research Council Committee to Reexamine IOMPWG: The National Academies Collection: Reports funded by National Institutes of Health. In: Weight Gain During Pregnancy: Reexamining the Guidelines. edn. Edited by Rasmussen KM, Yaktine AL. Washington (DC): National Academies Press (US) Copyright © 2009, National Academy of Sciences.; 2009.
2. Khan MN, Rahman MM, Shariff AA, Rahman MM, Rahman MS, Rahman MA. Maternal undernutrition and excessive body weight and risk of birth and health outcomes. Arch Public Health. 2017;75:12.
3. Sommer C, Sletner L, Mørkrid K, Jenum AK, Birkeland KI. Effects of early pregnancy BMI, mid-gestational weight gain, glucose and lipid levels in pregnancy on offspring's birth weight and subcutaneous fat: a population-based cohort study. BMC Pregnancy Childbirth. 2015;15:84.
4. Goldstein RF, Abell SK, Ranasinha S, Misso M, Boyle JA, Black MH, Li N, Hu G, Corrado F, Rode L, et al. Association of Gestational Weight Gain With Maternal and Infant Outcomes: A Systematic Review and Meta-analysis. JAMA. 2017;317(21):2207–25.
5. Asefa F, Cummins A, Dessie Y, Hayen A, Foureur M. Gestational weight gain and its effect on birth outcomes in sub-Saharan Africa: Systematic review and meta-analysis. PLoS ONE. 2020;15(4): e0231889.
6. Wang D, Wang M, Darling AM, Perumal N, Liu E, Danaei G, Fawzi WW. Gestational weight gain in low-income and middle-income countries: a modelling analysis using nationally representative data. BMJ Glob Health. 2020;5(11).
7. Wanyama R, Obai G, Odongo P, Kagawa MN, Baingana RK. Are women in Uganda gaining adequate gestational weight? A prospective study in low income urban Kampala. Reprod Health. 2018;15(1):160.
8. Misgina KH, van der Beek EM, Boezen HM, Bezabih AM, Groen H. Preconception and prenatal factors influencing gestational weight gain: a prospective study in Tigray region, northern Ethiopia. BMC Pregnancy Childbirth. 2021;21(1):718.
9. Asefa F, Cummins A, Dessie Y, Foureur M, Hayen A. Patterns and predictors of gestational weight gain in Addis Ababa, Central Ethiopia: a prospective cohort study. Reprod Health. 2021;18(1):159.
10. Asefa F, Nemomsa D. Gestational weight gain and its associated factors in Harari Regional State: Institution based cross-sectional study, Eastern Ethiopia. Reprod Health. 2016;13(1):101.
11. Haugen M, Brantsæter AL, Winkvist A, Lissner L, Alexander J, Oftedal B, Magnus P, Meltzer HM. Associations of pre-pregnancy body mass index and gestational weight gain with pregnancy outcome and postpartum weight retention: a prospective observational cohort study. BMC Pregnancy Childbirth. 2014;14:201.
12. Desyibelew HD, Dadi AF. Burden and determinants of malnutrition among pregnant women in Africa: A systematic review and meta-analysis. PLoS ONE. 2019;14(9): e0221712.
13. Johnson J, Clifton RG, Roberts JM, Myatt L, Hauth JC, Spong CY, Varner MW, Wapner RJ, Thorp JM Jr, Mercer BM, et al. Pregnancy outcomes with weight gain above or below the 2009 Institute of Medicine guidelines. Obstet Gynecol. 2013;121(5):969–75.
14. Chung JG, Taylor RS, Thompson JM, Anderson NH, Dekker GA, Kenny LC, McCowan LM. Gestational weight gain and adverse pregnancy outcomes in a nulliparous cohort. Eur J Obstet Gynecol Reprod Biol. 2013;167(2):149–53.
15. Ashley-Martin J, Woolcott C. Gestational weight gain and postpartum weight retention in a cohort of Nova Scotian women. Matern Child Health J. 2014;18(8):1927–35.
16. World Health Organization. Global Nutrition Targets 2025: Low birth weight policy brief. 2014. Available at https://www.who.int/publications/i/item/WHO-NMH-NHD-14.5.
17. Central Statistical Agency I: Federal Democratic Republic of Ethiopia, Central Statistical Agency, Ethiopia Demographic and Health Survey, Addis Ababa, Ethiopia. The DHS Program ICF Rockville, Maryland, USA, 2017 2016.
18. Khan A, Nasrullah FD, Jaleel R. Frequency and risk factors of low birth weight in term pregnancy. Pak J Med Sci. 2016;32(1):138–42.
19. Endalamaw A, Engeda EH, Ekubagewargies DT, Belay GM, Tefera MA. Low birth weight and its associated factors in Ethiopia: a systematic review and meta-analysis. Ital J Pediatr. 2018;44(1):141.
20. Gu H, Wang L, Liu L, Luo X, Wang J, Hou F, Nkomola PD, Li J, Liu G, Meng H, et al. A gradient relationship between low birth weight and IQ: A meta-analysis. Sci Rep. 2017;7(1):18035.
21. Islam MM. The effects of low birth weight on school performance and behavioral outcomes of elementary school children in Oman. Oman Med J. 2015;30(4):241.
22. Engidaw MT, Eyayu T, Tiruneh T. The effect of maternal anaemia on low birth weight among newborns in Northwest Ethiopia. Sci Rep. 2022;12(1):15280.
23. Siyoum M, Melese T. Factors associated with low birth weight among babies born at Hawassa University Comprehensive Specialized Hospital, Hawassa, Ethiopia. Ital J Pediatr. 2019;45(1):48.

24. Adane AA, Ayele TA, Ararsa LG, Bitew BD, Zeleke BM. Adverse birth outcomes among deliveries at Gondar University Hospital. Northwest Ethiopia BMC Pregnancy Childbirth. 2014;14:90.
25. Zenebe K, Awoke T, Birhan N. Low birth weight & associated factors among newborns in Gondar town, North West Ethiopia: institutional based cross-sectional study. Indo Global J Pharm. 2014;4(2):74–80.
26. Desalegn M, Terefe B, Bikila H. Effect of Food Insecurity and Other Possible Factors Associated with Low Birth Weight Among Mothers Who Gave Birth to Live Newborns in West Ethiopia: A Facility-Based Unmatched Case-Control Study. Nutr Diet Suppl. 2021;13:133–43.
27. Asayehu TT, Lachat C, Henauw S, Gebreyesus SH. Dietary behaviour, food and nutrient intake of women do not change during pregnancy in Southern Ethiopia. Matern Child Nutr. 2017;13(2).
28. Diddana TZ. Factors associated with dietary practice and nutritional status of pregnant women in Dessie town, northeastern Ethiopia: a community-based cross-sectional study. BMC Pregnancy Childbirth. 2019;19(1):517.
29. Spronk I, Kullen C, Burdon C, O'Connor H. Relationship between nutrition knowledge and dietary intake. Br J Nutr. 2014;111(10):1713–26.
30. Glanz K, Rimer BK, Viswanath K. Health behavior and health education: theory, research, and practice. Wiley; 2008. Available at https://books.google.de/books/about/Health_Behavior_and_Health_Education.html?id=1xuGErZCfbsC&redir_esc=y.
31. Chitsaz A, Javadi M, Lin C-Y, Pakpour A. The predictors of healthy eating behavior among pregnant women: An application of the theory of planned behavior. Int J Pediatr. 2017;5(10):5897–905.
32. Demilew YM, Alene GD, Belachew T. Dietary practices and associated factors among pregnant women in West Gojjam Zone, Northwest Ethiopia. BMC Pregnancy Childbirth. 2020;20(1):18.
33. World Health Organization. WHO recommendations on antenatal care for a positive pregnancy experience. World Health Organization; 2016. Available at https://www.who.int/publications/i/item/9789241549912.
34. Kastro S, Demissie T, Yohannes B. Low birth weight among term newborns in Wolaita Sodo town, South Ethiopia: a facility based cross-sectional study. BMC Pregnancy Childbirth. 2018;18(1):160.
35. da Silva LK, Ota E, Shakya P, Dagvadorj A, Balogun OO, Peña-Rosas JP, De-Regil LM, Mori R. Effects of nutrition interventions during pregnancy on low birth weight: an overview of systematic reviews. BMJ Glob Health. 2017;2(3): e000389.
36. Nyamasege CK, Kimani-Murage EW, Wanjohi M, Kaindi DWM, Ma E, Fukushige M, Wagatsuma Y. Determinants of low birth weight in the context of maternal nutrition education in urban informal settlements. Kenya J Dev Orig Health Dis. 2019;10(2):237–45.
37. Girma Beressa, Susan Joyce Whiting, Tefera Belachew: Effect of nutrition education integrating the health belief model and theory of planned behavior on dietary diversity of pregnant women in Southeast Ethiopia: a cluster randomized controlled trial. Nutrition Journal. 2024,23(1).
38. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods. 2007;39(2):175–91.
39. Jackson DL. Sample size and number of parameter estimates in maximum likelihood confirmatory factor analysis: A Monte Carlo investigation. Struct Equ Model. 2001;8(2):205–23.
40. Macías YF, Glasauer P. Guidelines for assessing nutrition-related knowledge, attitudes and practices: Food and Agriculture Organization of the United Nations; 2014. Available at https://www.fao.org/4/i3545e/i3545e00.htm.
41. Federal Ministry of Health: Federal Democratic Republic of Ethiopia, Training of trainers manual for counseling on maternal, infant and young child nutrition. 2011. Available at https://www.iycn.org/files/IYCN_MIYCN_Ethiopia_Counseling_TOT_Manual_1211.pdf.
42. Assefa Y, Gelaw YA, Hill PS, Taye BW, Van Damme W. Community health extension program of Ethiopia, 2003–2018: successes and challenges toward universal coverage for primary healthcare services. Global Health. 2019;15(1):24.
43. Demilew YM, Alene GD, Belachew T. Effects of guided counseling during pregnancy on birth weight of newborns in West Gojjam Zone, Ethiopia: a cluster-randomized controlled trial. BMC Pediatr. 2020;20(1):466.
44. Gizaw B, Gebremedhin S. Factors associated with low birthweight in North Shewa zone, Central Ethiopia: case-control study. Ital J Pediatr. 2018;44(1):76.
45. Alamneh AA, Endris BS, Gebreyesus SH. Caffeine, alcohol, khat, and tobacco use during pregnancy in Butajira, South Central Ethiopia. PLoS ONE. 2020;15(5): e0232712.
46. Kennedy G, Ballard T, Dop MC. Guidelines for measuring household and individual dietary diversity: Food and Agriculture Organization of the United Nations; 2011. Available https://www.fao.org/4/i1983e/i1983e00.pdf.
47. Belachew T, Lindstrom D, Gebremariam A, Hogan D, Lachat C, Huybregts L, Kolsteren P. Food insecurity, food based coping strategies and suboptimal dietary practices of adolescents in Jimma zone Southwest Ethiopia. PLoS ONE. 2013;8(3): e57643.
48. Tang AM, Chung M, Dong K, Terrin N, Edmonds A, Assefa N, Chetty T, Ramlal R, Christian P, West K, Janjua N, Wanke C, Deitchler M, Maalouf-Manasseh Z. Determining a global mid-upper arm circumference cutoff to assess malnutrition in pregnant women. Washington, DC: FHI 360. Food and Nutrition Technical Assistance III Project (FANTA); 2016. Available at https://www.fantaproject.org/sites/default/files/resources/FANTA-MUAC-cutoffs-pregnant-women-June2016.pdf.
49. Fakier A, Petro G, Fawcus S. Mid-upper arm circumference: A surrogate for body mass index in pregnant women. S Afr Med J. 2017;107(7):606–10.
50. Ghosh S, Spielman K, Kershaw M, Ayele K, Kidane Y, Zillmer K, Wentworth L, Pokharel A, Griffiths JK, Belachew T, et al. Nutrition-specific and nutrition-sensitive factors associated with mid-upper arm circumference as a measure of nutritional status in pregnant Ethiopian women: Implications for programming in the first 1000 days. PLoS ONE. 2019;14(3): e0214358.
51. Beressa G, Whiting SJ, Bealchew T. Effect of nutrition education on hemoglobin level of pregnant women in Southeast Ethiopia: a cluster randomized controlled trial. BMC Public Health. 2025;25(1).
52. Belachew T, Lindstrom D, Hadley C, Gebremariam A, Kasahun W, Kolsteren P. Food insecurity and linear growth of adolescents in Jimma Zone. Southwest Ethiopia Nutr J. 2013;12:55.
53. Coates J, Swindale A, Bilinsky P. Household Food Insecurity Access Scale (HFIAS) for measurement of food access: indicator guide: version 3. 2007. Available at https://www.fantaproject.org/sites/default/files/resources/HFIAS_ENG_v3_Aug07.pdf.
54. Zelalem T, Mikyas A, Erdaw T. Nutritional knowledge, attitude and practices among pregnant women who attend antenatal care at public hospitals of Addis Ababa, Ethiopia. International Journal of Nursing and Midwifery. 2018;10(7):81–9.
55. World Health Organization. Guideline: Daily iron and folic acid supplementation in pregnant women. World Health Organization; 2012. Available at https://www.who.int/publications/i/item/9789241501996.
56. Tafere TE, Afework MF, Yalew AW. Providers adherence to essential contents of antenatal care services increases birth weight in Bahir Dar City Administration, north West Ethiopia: a prospective follow up study. Reprod Health. 2018;15(1):163.
57. Jung SJ. Introduction to Mediation Analysis and Examples of Its Application to Real-world Data. J Prev Med Public Health. 2021;54(3):166–72.
58. Psy N. Structural Equation Modeling, SEM with Nonnormal Continuous Variables. 2023:7-9. Available at https://web.pdx.edu/~newsomj/semclass/ho_nonnormal.pdf.
59. Doustmohammadian A, Omidvar N, Keshavarz-Mohammadi N, Eini-Zinab H, Amini M, Abdollahi M. The association and mediation role of Food and Nutrition Literacy (FNLIT) with eating behaviors, academic achievement and overweight in 10–12 years old students: a structural equation modeling. Nutr J. 2022;21(1):45.
60. Kwok OM, Cheung MWL, Jak S, Ryu E, Wu JY. Editorial: Recent Advancements in Structural Equation Modeling (SEM): From Both Methodological and Application Perspectives. Front Psychol. 1936;2018:9.
61. Marsh HW, Morin AJ, Parker PD, Kaur G. Exploratory structural equation modeling: an integration of the best features of exploratory and confirmatory factor analysis. Annu Rev Clin Psychol. 2014;10:85–110.
62. Castro MA, Baltar VT, Marchioni DM, Fisberg RM. Examining associations between dietary patterns and metabolic CVD risk factors: a novel use of structural equation modelling. Br J Nutr. 2016;115(9):1586–97.
63. Hoyle RH. Handbook of structural equation modeling. Guilford press; 2012.
64. Muthén KL, Muthén BO. The comprehensive modeling program for applied researchers. Mplus user's guide (eight edition)[Computer software manual]. Los Angeles: 2017. Available at https://scholar.google.com/citations?view_op=view_citation&hl=en&user=d4u38H4AAAAJ&citation_for_view=d4u38H4AAAAJ:70eg2SAEIzsC.

65. Gunzler DD, Perzynski AT, Carle AC. Structural equation modeling for health and medicine. CRC Press; 2021. Available at https://www.taylorfrancis.com/books/mono/10.1201/9780203701133/structural-equation-modeling-health-medicine-douglas-gunzler-adam-perzynski-adam-carle.
66. Field-Fote EE. Mediators and Moderators, Confounders and Covariates: Exploring the Variables That Illuminate or Obscure the "Active Ingredients" in Neurorehabilitation. J Neurol Phys Ther. 2019;43(2):83–4.
67. Darling AM, Wang D, Perumal N, Liu E, Wang M, Ahmed T, Christian P, Dewey KG, Kac G, Kennedy SH, et al. Risk factors for inadequate and excessive gestational weight gain in 25 low- and middle-income countries: An individual-level participant meta-analysis. PLoS Med. 2023;20(7): e1004236.
68. Omer AM, Haile D, Shikur B, Macarayan ER, Hagos S: Effectiveness of a nutrition education and counselling training package on antenatal care: a cluster randomized controlled trial in Addis Ababa. Health Policy Plan 2020, 35(Supplement_1):i65-i75.
69. Soliman A-Z, Hassan A, Fahmy HH. Effect of Nutritional Education Intervention on Knowledge, Attitude and Practice of Pregnant Women towards Dietary habits, Physical activity and Optimal Gestational Weight Gain. Zagazig University Medical Journal. 2021;27(4):577–88.
70. von Salmuth V, Brennan E, Kerac M, McGrath M, Frison S, Lelijveld N. Maternal-focused interventions to improve infant growth and nutritional status in low-middle income countries: A systematic review of reviews. PLoS ONE. 2021;16(8): e0256188.
71. Goodarzi-Khoigani M, Moghadam MHB, Nadjarzadeh A, Mardanian F, Fallahzadeh H, Mahmoodabad SSM. Prevention of Excessive Gestational Weight Gain by Nutrition Education Intervention: A Randomized Controlled Trial. Health Scope. 2018;7(3).
72. Akter SM, Roy SK, Thakur SK, Sultana M, Khatun W, Rahman R, Saliheen SS, Alam N. Effects of third trimester counseling on pregnancy weight gain, birthweight, and breastfeeding among urban poor women in Bangladesh. Food Nutr Bull. 2012;33(3):194–201.
73. Jahan K, Roy SK, Mihrshahi S, Sultana N, Khatoon S, Roy H, Datta LR, Roy A, Jahan S, Khatun W, et al. Short-term nutrition education reduces low birthweight and improves pregnancy outcomes among urban poor women in Bangladesh. Food Nutr Bull. 2014;35(4):414–21.
74. Aşcı Ö, Rathfisch G. Effect of lifestyle interventions of pregnant women on their dietary habits, lifestyle behaviors, and weight gain: a randomized controlled trial. J Health Popul Nutr. 2016;35:7.
75. Zelalem A, Endeshaw M, Ayenew M, Shiferaw S, Yirgu R. Effect of nutrition education on pregnancy specific nutrition knowledge and healthy dietary practice among pregnant women in Addis Ababa. Clinics in Mother and Child Health. 2017;14(3):265.
76. Girard AW, Olude O. Nutrition education and counselling provided during pregnancy: effects on maternal, neonatal and child health outcomes. Paediatr Perinat Epidemiol. 2012;26(Suppl 1):191–204.
77. Demilew YM, Alene GD, Belachew T. Effect of guided counseling on dietary practices of pregnant women in West Gojjam Zone, Ethiopia. PLoS ONE. 2020;15(5): e0233429.
78. Downe S, Finlayson K, Tunçalp Ö, Metin Gülmezoglu A. What matters to women: a systematic scoping review to identify the processes and outcomes of antenatal care provision that are important to healthy pregnant women. BJOG. 2016;123(4):529–39.
79. Polley BA, Wing RR, Sims CJ. Randomized controlled trial to prevent excessive weight gain in pregnant women. Int J Obes Relat Metab Disord. 2002;26(11):1494–502.
80. Althuizen E, van der Wijden CL, van Mechelen W, Seidell JC, van Poppel MN. The effect of a counselling intervention on weight changes during and after pregnancy: a randomised trial. BJOG. 2013;120(1):92–9.
81. Martínez-Hortelano JA, Cavero-Redondo I, Álvarez-Bueno C, Garrido-Miguel M, Soriano-Cano A, Martínez-Vizcaíno V. Monitoring gestational weight gain and prepregnancy BMI using the 2009 IOM guidelines in the global population: a systematic review and meta-analysis. BMC Pregnancy Childbirth. 2020;20(1):649.
82. Hui A, Back L, Ludwig S, Gardiner P, Sevenhuysen G, Dean H, Sellers E, McGavock J, Morris M, Bruce S, et al. Lifestyle intervention on diet and exercise reduced excessive gestational weight gain in pregnant women under a randomised controlled trial. BJOG. 2012;119(1):70–7.
83. Lien N, Lytle LA, Komro KA. Applying theory of planned behavior to fruit and vegetable consumption of young adolescents. Am J Health Promot. 2002;16(4):189–97.
84. Tsegaye D, Tamiru D, Belachew T: Effect of a theory-based nutrition education intervention during pregnancy through male partner involvement on newborns' birth weights in Southwest Ethiopia. A three-arm community based Quasi-Experimental study. PLoS One 2023, 18(1):e0280545.
85. Habtu M, Agena AG, Umugwaneza M, Mochama M, Munyanshongore C. Effectiveness of Integrated Maternal Nutrition Intervention Package on Birth Weight in Rwanda. Front Nutr. 2022;9: 874714.
86. Chowdhury M, Raynes-Greenow C, Kelly P, Alam NA, Afsana K, Billah SM, Dibley MJ. The Impact of Antenatal Balanced Plate Nutrition Education for Pregnant Women on Birth Weight: A Cluster Randomised Controlled Trial in Rural Bangladesh. Nutrients. 2022;14(21).
87. Bhutta ZA, Das JK, Rizvi A, Gaffey MF, Walker N, Horton S, Webb P, Lartey A, Black RE, Group LNIR. Evidence-based interventions for improvement of maternal and child nutrition: what can be done and at what cost? The lancet. 2013;382(9890):452–77.
88. Ruel MT, Alderman H. Nutrition-sensitive interventions and programmes: how can they help to accelerate progress in improving maternal and child nutrition? Lancet. 2013;382(9891):536–51.
89. Nikièma L, Huybregts L, Martin-Prevel Y, Donnen P, Lanou H, Grosemans J, Offoh P, Dramaix-Wilmet M, Sondo B, Roberfroid D, et al. Effectiveness of facility-based personalized maternal nutrition counseling in improving child growth and morbidity up to 18 months: A cluster-randomized controlled trial in rural Burkina Faso. PLoS ONE. 2017;12(5): e0177839.
90. Berhe K, Weldegerima L, Gebrearegay F, Kahsay A, Tesfahunegn A, Rejeu M, Gebremariam B. Effect of under-nutrition during pregnancy on low birth weight in Tigray regional state, Ethiopia; a prospective cohort study. BMC Nutr. 2021;7(1):72.
91. Adane T, Dachew BA. Low birth weight and associated factors among singleton neonates born at Felege Hiwot referral hospital. North West Ethiopia Afr Health Sci. 2018;18(4):1204–13.
92. Demelash H, Motbainor A, Nigatu D, Gashaw K, Melese A. Risk factors for low birth weight in Bale zone hospitals, South-East Ethiopia : a case-control study. BMC Pregnancy Childbirth. 2015;15:264.
93. Kaveh MH, Layeghiasl M, Nazari M, Ghahremani L, Karimi M. What Are the Determinants of a Workplace Health Promotion? Application of a Social Marketing Model in Identifying Determinants of Physical Activity in the Workplace (a Qualitative Study). Front Public Health. 2020;8: 614631.
94. Eldridge S, Ashby D, Bennett C, Wakelin M, Feder G. Internal and external validity of cluster randomised trials: systematic review of recent trials. Bmj. 2008;336(7649):876-80.
95. Bollen KA: Structural equations with latent variables, vol. 210: John Wiley & Sons; 1989.
96. Food and Agriculture Organization. Minimum dietary diversity for women: a guide for measurement. Rome: FAO; 2016. p. 82.
97. Blakely T, McKenzie S, Carter K. Misclassification of the mediator matters when estimating indirect effects. J Epidemiol Community Health. 2013;67(5):458–66.
98. World Medical Association Declaration of Helsinki. ethical principles for medical research involving human subjects. JAMA. 2013;310(20):2191–4.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.