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ANISA-Based Nutrition Education and Hemoglobin Concentration Among Pregnant Women Receiving Routine Iron Supplementation: A Controlled Quasi-Experimental Study

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ABSTRACT

Digital nutrition education may improve adherence to iron supplementation during pregnancy. This controlled quasi-experimental study compared ANISA-based nutrition education combined with routine iron supplementation with leaflet-based education delivered alongside the same supplementation program. A total of 100 pregnant women in their second or third trimester (50 per group) were recruited from four primary healthcare centers (PHCs) in Merangin District, Indonesia, and followed for eight weeks. The primary outcome was hemoglobin concentration measured using capillary blood at baseline and follow-up. Mean hemoglobin levels increased by 0.98 ± 0.55 g/dL in the ANISA group and 0.46 ± 0.52 g/dL in the leaflet group. The reported adjusted difference in follow-up hemoglobin was 0.50 g/dL (95% CI 0.29–0.71; $p < 0.001$). At follow-up, anemia prevalence was 36.0% in the ANISA group and 58.0% in the leaflet group, with a reported adjusted risk ratio of 0.62 (95% CI 0.40–0.96; $p = 0.033$). Iron-tablet adherence was higher in the ANISA group (91.2 ± 8.6%) than in the leaflet group (76.8 ± 13.4%). Although baseline nutrition knowledge was higher in the ANISA group, the mean increases in knowledge scores were comparable between groups (19.30 and 19.90 points, respectively). Overall, ANISA-based education was associated with greater improvements in hemoglobin levels and higher iron-tablet adherence than leaflet-based education. However, the findings do not establish superior knowledge improvement or a causal intervention effect.

INTRODUCTION

Pregnancy increases maternal iron requirements to support erythropoiesis and fetal development, while plasma-volume expansion can lower hemoglobin concentration. Maternal anemia has multiple nutritional and non-nutritional causes and is associated with adverse pregnancy outcomes [1,2,3]. The 2024 World Health Organization (WHO) guideline defines anemia using gestational-age-specific hemoglobin thresholds; the second-trimester threshold differs from that used in the third trimester [4].

WHO recommends daily oral supplementation with 30–60 mg elemental iron and 400 µg folic acid during pregnancy [5,6]. Provision of tablets alone does not ensure that the prescribed doses are taken. Repeated education, practical management of adverse effects, and adherence support may improve supplement-taking behavior. Digital messages and reminders can provide reinforcement between antenatal visits, although their contribution must be evaluated using both behavioral and hematologic outcomes [7,8].

The burden remains substantial. WHO estimated that 35.5% of pregnant women worldwide had anemia in 2023 [9]. Indonesia's 2023 Health Survey reported anemia in 27.7% of pregnant women [10]. The submitted manuscript cites local service records reporting 5.47% in Jambi Province and 497 cases among 6,919 pregnancies in Merangin District in 2024 (7.18%). These service-based proportions are not directly comparable with survey prevalence because they depend on testing and reporting coverage. A preliminary assessment reportedly found limited anemia-prevention knowledge in 29 of 40 pregnant women; the underlying local records and assessment instrument require author verification.

Persistent anemia alongside supplementation programs suggests that access to tablets may not consistently translate into sustained intake. Women may discontinue tablets because of gastrointestinal symptoms, forget doses, or have difficulty applying dietary advice. Digital education can provide repeated messages and cues to action, but improved knowledge alone does not establish an effect on hemoglobin. Supplementation exposure, outcome measurement, and alternative causes of anemia must also be considered [7,11,8].

International evidence suggests benefits from nutrition education and supplement-adherence support, although interventions and effects vary substantially. A systematic review included 53 studies involving 13,475 pregnant women and evaluated iron–folic acid adherence, hemoglobin, and anemia [12]. Studies in Ethiopia and Nepal have also examined nutrition counseling or education with clinical hemoglobin outcomes [13,14,15]. These findings support evaluation of locally implemented digital programs but do not establish that any specific application will reproduce the same effect.

ANISA (Antisipasi Ibu Hamil Sadar Anemia) is the Android-based education application evaluated in this study. Its reported functions include nutrition messages, iron-tablet reminders, intake recording, hemoglobin recording, consultation, and feedback. The application records information and supports communication; hemoglobin measurement and clinical diagnosis remain the responsibility of qualified healthcare personnel. The developer, development process, and status of ANISA as a research intervention or an existing service must be confirmed from the project records.

This study compared ANISA-based nutrition education plus routine iron supplementation with leaflet-based education plus the same supplementation program. The primary clinical outcome was hemoglobin concentration at eight weeks, interpreted in relation to baseline concentration. Secondary outcomes were anemia prevalence, adherence to prescribed iron tablets, and anemia-prevention knowledge. The association between adherence and hemoglobin change was exploratory. Because allocation was nonrandom, findings were interpreted as associations, with particular attention to baseline imbalance and possible confounding by healthcare center.

MATERIALS AND METHODS

Study Design

This was a two-arm controlled quasi-experimental pretest–posttest study. Participants received ANISA-based nutrition education plus routine iron supplementation or leaflet-based education plus routine supplementation. There was no individual randomization or allocation concealment. The study therefore does not provide the same protection against confounding as a randomized trial. Reporting was aligned with the TREND statement and risk-of-bias domains for quasi-experimental studies [16,17]. The intervention description was organized by provider, content, delivery, frequency, and monitoring using TIDieR principles [18].

Study Setting and Period

The study was conducted in Merangin District, Jambi Province, Indonesia, at Bangko, Pematang Kandis, Muara Jernih, and Muara Delang primary healthcare centers (PHCs). The calendar period is March–June 2025. Each participant was followed for eight weeks; this is the intervention duration, not eight months. Eight weeks allows assessment of a short-term hemoglobin response over several weeks of supplementation, but does not establish sustained benefit through delivery or postpartum [5,19]. The actual protocol rationale for selecting this duration must be confirmed.

Population and Sample

The target population comprised pregnant women receiving antenatal care in Merangin District, Jambi Province, Indonesia. The accessible population consisted of 4,588 pregnant women registered across 27 primary healthcare centers (PHCs). Women were eligible if they were permanent residents, were in the second or third trimester of pregnancy, were receiving routine oral iron supplementation, owned an Android smartphone, and provided written informed consent. Exclusion criteria included planned relocation during follow-up, documented hemoglobinopathy, active major bleeding, severe infection, chronic renal disease, or treatment requiring parenteral iron or blood transfusion.

Here, (n) represents the required sample per group, (\sigma) the assumed common standard deviation, and (\Delta) the between-group difference to be detected. Assuming a standard deviation of 0.70 g/dL, a difference of 0.40 g/dL, a two-sided significance level of 0.05, and 80% power, the calculation yielded approximately 48.1 participants per group. This was rounded upward to 49, and the recruitment target was set at 50 participants per group, resulting in 100 participants overall. No separate percentage-based allowance for attrition was applied. This calculation assumed independent observations and did not incorporate an adjustment for PHC-level clustering.

Sampling and Group Formation

Four primary healthcare centers (PHCs) Bangko, Pematang Kandis, Muara Jernih, and Muara Delang were purposively selected based on the availability of routine antenatal services, an

established iron-supplementation program, and operational capacity to support intervention delivery and eight-week follow-up. These criteria reflected study feasibility and did not establish equivalence between the participating facilities. Within the selected PHCs, eligible pregnant women were recruited consecutively during antenatal visits until the target sample was reached. The final sample comprised 24 participants from Bangko, 28 from Pematang Kandis, 25 from Muara Jernih, and 23 from Muara Delang, yielding 100 participants overall.

Group assignment was nonrandom and based on designated service subareas within the participating PHCs, rather than assignment of each entire PHC to a single study arm. Consequently, participants from the same PHC could belong to either group. Fifty women received ANISA-based nutrition education plus routine iron supplementation, and 50 received leaflet-based education plus the same supplementation program. No participant-level random sequence or allocation concealment was used. Separate delivery within designated service subareas and restricted ANISA access were used to reduce potential crossover between groups. Identical eligibility criteria and outcome-measurement procedures were applied to both groups. Nevertheless, differences in geographic accessibility, staffing, service delivery, and supplementation availability could contribute to confounding and were considered limitations of the nonrandomized design.

Intervention

Both groups received routine antenatal care and oral iron–folic acid supplementation throughout the eight-week intervention period. The prescribed regimen was one tablet daily containing 200 mg ferrous sulfate and 0.25 mg folic acid. The ferrous sulfate amount represents the iron-salt mass rather than the elemental-iron content. Supplementation was provided through routine antenatal services and was identical in both groups.

ANISA intervention group. Participants received additional nutrition education through ANISA (Antisipasi Ibu Hamil Sadar Anemia), an Android application developed by the research team to support anemia prevention and adherence to prescribed iron tablets. Before recruitment, the research team trained the participating midwives in application navigation, educational content, participant orientation, intake recording, dashboard review, and follow-up procedures. Training included demonstrations and supervised practice to promote consistent delivery. At enrollment, each participant attended an individual, midwife-led orientation lasting approximately 30–45 minutes. The session addressed anemia during pregnancy, iron-rich foods, dietary factors affecting iron absorption, correct supplement use, management of common adverse effects, and indications for seeking clinical care. Participants also practiced accessing educational materials, responding to reminders, and completing the tablet-intake checklist. During the following eight weeks, participants were encouraged to access ANISA daily and review educational content each week. Materials were delivered through concise text, images, and videos covering anemia prevention, dietary iron intake, supplement-taking

practices, and management of difficulties encountered during supplementation. Weekly review allowed participants to revisit relevant materials; it did not necessarily represent a different module each week.

ANISA provided a daily supplement reminder and a checklist for self-recording tablet intake. These entries represented participant-reported consumption rather than directly observed ingestion. Midwives reviewed the application dashboard weekly to identify incomplete records and potential adherence difficulties. Three consecutive days without an intake entry prompted follow-up contact to clarify whether tablets had been missed, records had not been completed, or technical problems had occurred. Participants could also submit questions through the consultation function, with individualized feedback provided by the participating midwives.

Implementation was documented using orientation checklists, application activity logs, and weekly monitoring records. These records were used to describe delivery and participant engagement, including educational-content access, intake recording, and follow-up contacts. Application access alone was not interpreted as evidence that educational material had been understood or tablets had been consumed.

Comparison group. Participants received routine antenatal counseling and an anemia-prevention leaflet alongside the same iron–folic acid supplementation regimen. The leaflet addressed anemia prevention, dietary iron sources, and correct supplement use. Counseling was delivered by antenatal-care staff during routine visits. Participants did not receive ANISA access, application-generated reminders, or dashboard-based monitoring during follow-up.

Routine clinical management remained available to both groups. Additional supplementation, treatment for infection, hospitalization, transfusion, and external nutrition counseling were documented when reported or identified in clinical records. Women requiring further assessment or treatment were referred according to local clinical procedures.

Outcomes and Variables

The primary outcome was capillary hemoglobin concentration (g/dL) at eight weeks, evaluated in relation to baseline hemoglobin concentration. Hemoglobin change was calculated by subtracting baseline concentration from the eight-week concentration. Secondary outcomes were anemia prevalence, adherence to prescribed iron tablets, and anemia-prevention knowledge.

Anemia was defined using trimester-specific thresholds: hemoglobin <10.5 g/dL during the second trimester and <11.0 g/dL during the third trimester, consistent with the 2024 WHO guideline. Gestational age at each hemoglobin measurement determined the applicable threshold; therefore, participants who progressed from the second to the third trimester during follow-up were classified using the threshold corresponding to their trimester at that assessment [4].

Adherence (%) was calculated as the number of prescribed tablets recorded as consumed divided by the number prescribed during the participant's observation period, multiplied by 100. An uninterrupted eight-week prescription of one tablet daily corresponded to 56 prescribed tablets. Any documented changes in the prescribed regimen or observation period were reflected in the denominator. Intake was recorded through the ANISA application in the intervention group and paper-based records in the comparison group. These records represented self-reported intake rather than directly observed consumption. Missing entries were distinguished from explicitly reported missed doses.

Where returned-tablet counts were available, they were used as supplementary checks against intake records. Tablet reconciliation considered the opening stock, additional tablets supplied, closing stock, and documented losses or transfers. Tablets that were not returned were not automatically classified as consumed. Any unresolved discrepancies were retained as uncertain intake rather than assumed adherence.

Anemia-prevention knowledge was measured using a questionnaire scored from 0 to 100, with higher scores indicating greater knowledge. Baseline hemoglobin concentration, gestational age, education, employment, previous-child status, and PHC identity were recorded as potential confounders. Gestational age referred to pregnancy duration at assessment. Previous-child status indicated whether the participant had a previous child and was not treated as equivalent to obstetric parity. PHC identity identified the individual recruitment center Bangko, Pematang Kandis, Muara Jernih, or Muara Delang and was distinguished from intervention-group assignment. Recording these variables as potential confounders did not imply that all were included in the adjusted statistical model.

Data Collection and Measurement

Hemoglobin concentration was measured using capillary blood samples obtained through finger-prick procedures and analyzed using a HemoCue Hb 201+ analyzer. All measurements were performed according to the manufacturer's operating instructions by trained healthcare personnel who had received standardized training in capillary blood collection, sample handling, analyzer operation, and result recording. Before each measurement, the participant's finger was cleaned and allowed to dry. The first blood drop was discarded, and the subsequent blood sample was collected using a compatible microcuvette. The microcuvette was filled completely, avoiding air bubbles, and immediately analyzed. Hemoglobin concentrations were recorded in g/dL.

Quality control procedures included checking the analyzer's operational condition, inspecting microcuvettes for damage and expiration dates, verifying the instrument's display and measurement readiness, and conducting control checks in accordance with the manufacturer's recommendations. Measurement results were documented immediately on standardized data collection forms. Any instrument error, incomplete sample, or questionable measurement was recorded and addressed

through repeat measurement after checking the sampling and analyzer procedures. All measurements were conducted using the same standardized protocol to minimize inter-operator and measurement variability.

Knowledge regarding anemia and nutritional prevention was assessed using a researcher-developed questionnaire consisting of 20 items. The questionnaire covered five domains: (1) basic knowledge of anemia; (2) causes and risk factors of anemia; (3) signs, symptoms, and health consequences; (4) nutritional sources of iron and dietary practices; and (5) anemia prevention and iron supplementation during pregnancy. Each item was scored dichotomously, with 1 point assigned to a correct answer and 0 points to an incorrect or uncertain answer. The total score ranged from 0 to 20 and was transformed into a 0–100 scale using the following formula:

Knowledge score = (Number of correct answers / 20) × 100.

Higher scores indicated better knowledge regarding anemia prevention and nutritional practices. Content validity was addressed through expert review of the questionnaire to evaluate item relevance, clarity, comprehensiveness, and consistency with the study objectives. The review process considered the appropriateness of the language and cultural context for the target population. Items requiring clarification or revision were reviewed before the questionnaire was finalized. The questionnaire was subsequently subjected to pilot testing to assess comprehensibility, response procedures, and the feasibility of administration. Internal consistency was intended to be evaluated using an appropriate reliability coefficient for dichotomously scored items, such as the Kuder–Richardson Formula 20 (KR-20).

Baseline and follow-up assessments used the same questionnaire, with identical item content, response options, and scoring procedures to maintain measurement consistency over time. Data collection was conducted by a trained research team with responsibilities assigned according to the measurement procedures. Hemoglobin operators were responsible for collecting capillary blood samples and operating the HemoCue Hb 201+ analyzer. Questionnaire assessors were responsible for explaining the questionnaire, assisting participants when necessary, and ensuring that responses were completed consistently. Enumerators were responsible for participant identification, administering and recording questionnaire data, checking completeness, and maintaining the study database. These responsibilities were standardized through pre-data-collection training and the use of structured operating procedures.

To reduce measurement and information bias, all personnel followed the same data collection protocol. Where feasible, outcome assessors were kept unaware of participants' intervention allocation. Completed questionnaires and hemoglobin records were checked for completeness and consistency before data entry. Data discrepancies were reviewed against the original forms, and corrections were documented to maintain data accuracy and traceability.

Study Procedures

Potential participants were screened during routine antenatal care visits according to the study eligibility criteria. Eligible pregnant women received an explanation of the study objectives, procedures, potential benefits, and possible risks before providing written informed consent. Baseline assessments were conducted before the initiation of the study-specific educational intervention and included sociodemographic and obstetric characteristics, hemoglobin concentration, anemia classification, anemia-related knowledge, iron supplementation history, and other relevant potential confounding variables.

Following baseline assessment, participants received the intervention according to their respective study groups. The intervention group received the ANISA (Anemia Information and Support Application) program for eight weeks in addition to routine antenatal care and standard iron–folic acid supplementation. At the beginning of the intervention, participants received an individual orientation session lasting approximately 30–45 minutes, conducted by trained midwives. This session introduced the application, its main features, and instructions for daily use.

The ANISA application provided structured anemia-related educational materials through text, images, and videos, including information on anemia prevention, iron-rich foods, appropriate dietary practices, and the importance of regular iron supplementation during pregnancy. Additional features included stage-specific motivational messages, daily medication reminders, an electronic supplement-intake checklist, a personal hemoglobin record, nutritional guidance, and a consultation function that enabled communication with healthcare personnel. Participants were encouraged to use the application daily and complete the relevant educational content and medication-intake records. Educational modules were reviewed weekly, while application dashboards and adherence records were monitored by the research team. Participants with three consecutive days of unrecorded medication intake received follow-up contact to identify potential barriers and encourage continued engagement.

The comparison group received routine antenatal care, standard iron–folic acid supplementation, and conventional anemia-prevention education delivered using printed leaflets. The educational materials addressed the same general topics covered by the ANISA program, including anemia awareness, dietary practices, and the importance of iron supplementation. However, participants in the comparison group did not receive access to the ANISA application or its digital reminder and monitoring features.

Throughout the eight-week intervention period, participants in both groups were contacted weekly to document iron supplement use, potential adverse effects, intercurrent illnesses, additional treatments, and continued participation. Information regarding adherence and other relevant events was recorded using standardized monitoring forms. Any concerning symptoms or clinically significant

anemia findings were managed through referral to healthcare services according to applicable clinical protocols. Routine antenatal care and iron–folic acid supplementation continued in both groups throughout the study.

At the end of the eight-week intervention, follow-up assessments were conducted using the same standardized procedures as at baseline. Hemoglobin concentration was reassessed using capillary blood samples analyzed with the HemoCue Hb 201+ analyzer, and anemia-related knowledge was reassessed using the same 20-item questionnaire. All measurements were recorded using unique participant identification codes to maintain confidentiality and facilitate linkage between baseline and follow-up records.

Participant records were reviewed for completeness and consistency before statistical analysis. The analysis population and denominator were determined separately for each outcome based on the availability of baseline and follow-up measurements. The primary-outcome analysis included all 100 enrolled participants with available baseline and eight-week hemoglobin measurements. Because complete primary-outcome measurements were available for these participants, no imputation of missing primary-outcome data was necessary. Missingness for secondary outcomes was assessed separately. Accordingly, the analysis was described as an analysis of participants with observed outcome measurements rather than an intention-to-treat analysis, as the study did not use randomized allocation.

Bias Control

Contamination refers to comparison participants receiving ANISA-specific materials or reminders, sharing intervention accounts, or receiving ANISA-based counseling from intervention staff. Separate service-area delivery and restricted application credentials were the measures reported to limit such crossover; these measures reduce opportunities for exposure but do not establish that contamination was absent. Participant contact across sites and actual crossover should be reported if measured. Standardized measurement procedures and assessor masking can reduce measurement bias, while written intervention materials and delivery records can document consistency; they cannot remove selection bias caused by nonrandom allocation [17,18,21]. Baseline employment, gestational-age distribution, and knowledge differed between groups. Adjustment requires verified participant-level data and an identifiable model. If each PHC contributed to only one arm, including fixed effects for all PHCs and group in the same model makes their effects inseparable. Four PHCs also provide limited support for conventional cluster-robust inference. Residual confounding, unequal contact, self-reported tablet intake, and possible contamination therefore remain important limitations [17,21].

Ethical Considerations

The submitted manuscript reports ethical approval from the PROMISE Health Research Ethics Committee, Kendari, Southeast Sulawesi, Indonesia (Approval No. 40/PROMISE/KEPK/I/2026). The institutional name must match the approval letter.provided written informed consent, and routine clinical care was not withheld.

Statistical Analysis

The submitted draft identifies IBM SPSS Statistics version 26.0 as the analysis software. Continuous outcomes are summarized as mean ± SD and categorical variables as n (%). At the reviewer's request, exploratory baseline comparisons were reconstructed from the reported summary statistics: Pearson χ^2 tests without continuity correction for categorical variables and Welch independent-samples t tests for hemoglobin and knowledge. These calculations use reported counts and rounded means and SDs; they do not account for within-PHC clustering and do not prove baseline equivalence. The proposed primary estimand is the between-group difference in eight-week hemoglobin concentration adjusted for baseline concentration and relevant pre-intervention covariates. Reported ANCOVA and robust-Poisson estimates have been retained provisionally in the results; the original analysis outputs, model specification, allocation level, and handling of PHC must be verified. Fixed PHC effects cannot be estimated separately from a group effect when group is constant within every PHC. Analysis of knowledge should adjust for baseline knowledge; a follow-up Mann–Whitney test alone does not establish an intervention-related gain. Group mean knowledge changes can be described, but their confidence intervals cannot be calculated without the SDs of within-person changes or the individual data. The reported correlation between iron-tablet adherence and hemoglobin change is exploratory and is not a mediation analysis. Two-sided $p < 0.05$ is used for exploratory comparisons, with effect estimates and 95% CIs where available. No missing primary outcomes were reported, so no imputation was undertaken.

RESULTS

Table 1. Baseline characteristics of the participants

Characteristics	Intervention (n=50)	Control (n=50)	p-value
Education, n (%)			0.900
Basic	21 (42.0)	19 (38.0)	
Secondary	24 (48.0)	25 (50.0)	
Higher	5 (10.0)	6 (12.0)	
Employment, n (%)			0.023
Not employed	32 (64.0)	42 (84.0)	
Employed	18 (36.0)	8 (16.0)	
Gestational age, n (%)			0.045
Second trimester	32 (64.0)	22 (44.0)	
Third trimester	18 (36.0)	28 (56.0)	
Previous-child status, n (%)			0.423
No previous child	28 (56.0)	24 (48.0)	

Has previous child	22 (44.0)	26 (52.0)	
Baseline Hb (g/dL), mean ± SD	10.48 ± 0.72	10.52 ± 0.70	0.779
Baseline anemia, n (%)	38 (76.0)	37 (74.0)	0.817
Baseline knowledge score, mean ± SD	69.60 ± 15.90	58.50 ± 14.37	<0.001

Table 1 shows that the groups differed in employment status, gestational age, and baseline knowledge scores. No statistically significant differences were observed in education, previous-child status, baseline hemoglobin, or baseline anemia status.

Table 2. Changes in hemoglobin concentration at baseline and after 8 weeks

Hemoglobin concentration	Intervention (n=50)	Control (n=50)	Mean difference (95% CI)	p-value
Baseline, mean ± SD	10.48 ± 0.72	10.52 ± 0.70	−0.04 (−0.32 to 0.24)	0.779
Follow-up, mean ± SD	11.46 ± 0.69	10.98 ± 0.72	0.48 (0.20 to 0.76)	0.001
Change, mean ± SD	0.98 ± 0.55	0.46 ± 0.52	0.52 (0.31 to 0.73)	<0.001
Adjusted follow-up difference	—	—	0.50 (0.29 to 0.71)	<0.001

At 8 weeks, mean hemoglobin increased in both groups, with a greater increase in the intervention group. The adjusted analysis also indicated a higher follow-up hemoglobin concentration in the intervention group (Table 2).

Table 3. Anemia status, iron supplementation adherence, and knowledge outcomes

Outcome	Intervention (n=50)	Control (n=50)	Effect estimate / mean difference (95% CI)	p-value
Anemia status, n (%)				
Baseline	38 (76.0)	37 (74.0)	—	0.817
Follow-up	18 (36.0)	29 (58.0)	Adjusted RR 0.62 (0.40–0.96)	0.033
Iron supplementation adherence (%)	91.2 ± 8.6	76.8 ± 13.4	14.4 (10.0–18.8)	<0.001
Knowledge score				
Baseline	69.60 ± 15.90	58.50 ± 14.37	—	<0.001
Follow-up	88.90 ± 9.49	78.40 ± 11.67	10.50	<0.001
Change from baseline	19.30	19.90	−0.60	Not tested
Exploratory correlation				
Adherence and Hb change	r = 0.46	—	95% CI 0.29–0.60	<0.001

At follow-up, anemia prevalence was lower and iron supplementation adherence was higher in the intervention group than in the control group. Knowledge scores were also higher at follow-up in the intervention group. However, the descriptive changes in knowledge scores were similar between groups, and no between-group test of change was available. Iron supplementation adherence was positively correlated with hemoglobin change; this finding represents an exploratory association rather than evidence of mediation (Table 3).

DISCUSSION

The clinical objective was to compare hemoglobin concentration following ANISA-based education plus routine iron supplementation with that following leaflet-based education plus the same

supplementation program. The observed mean hemoglobin increase was larger with ANISA, and the reported follow-up anemia prevalence was lower. Iron-tablet adherence was also higher. Knowledge improved in both groups, but the ANISA group started with higher knowledge and did not show a larger mean score increase. Consequently, the knowledge findings do not demonstrate superior intervention-related learning. Interpretation of adjusted hemoglobin and anemia estimates remains limited by unresolved site allocation and model verification.

The observed direction of the hemoglobin and adherence findings is consistent with education and supplement-support literature. Engidaw and colleagues synthesized 53 studies examining iron–folic acid adherence, hemoglobin, and anemia, while noting substantial heterogeneity [12]. Wakwoya and colleagues evaluated intensive nutrition education and counseling in Ethiopia [15]. Sunuwar and colleagues examined nutrition education with hemoglobin measurement in Nepal, and Adhikari and colleagues evaluated education combined with pill counting [14,13]. Elsharkawy and colleagues also evaluated an information package in pregnant women with anemia [22]. These studies support the plausibility of benefit but do not validate the present adjusted estimates.

Repeated education, reinforcement of supplement use, and continued contact are common components of adherence interventions during pregnancy [8,23]. ANISA combines these components within one Android application, according to the submitted intervention description. Differences between studies may reflect duration, baseline anemia, supplementation regimen, adherence measurement, and outcome ascertainment. The eight-week follow-up assesses a short-term outcome and does not establish persistence of benefit through delivery. The contribution of each ANISA component cannot be separated in this bundled comparison.

ANISA may connect education to hemoglobin response through several complementary steps. Information about anemia and supplement use may improve understanding and confidence; daily reminders may reduce forgotten doses; intake recording may make missed doses visible; and feedback or consultation may help participants manage difficulties. Sustained ingestion of the prescribed supplement can increase exposure to available iron, which supports hemoglobin synthesis [7,8,19]. These are plausible pathways, not mechanisms proven by this study. The moderate adherence–hemoglobin association is compatible with the pathway but cannot establish that adherence mediated an ANISA effect.

The discussion of biological benefit must remain closely linked to the observed supplement-taking outcome. Evidence on micronutrient-adherence interventions supports repeated counseling and practical assistance, while the WHO recommendation provides the preventive rationale for iron–folic acid supplementation [8,5]. ANISA's reported reminders, intake checklist, and feedback could have supported these behaviors. However, dietary change, absorption, actual elemental-iron exposure, and correction of iron deficiency were not established by hemoglobin alone. Nutritional factors other

than iron can also contribute to anemia [11]. The absence of ferritin and inflammatory markers therefore limits attribution of the observed hemoglobin change specifically to correction of iron deficiency.

The reported correlation between iron-tablet adherence and hemoglobin change is exploratory. Motivation, diet, household support, and access to services may be common causes of both outcomes. In addition, nonrandom service-area allocation can produce confounding by site and by baseline participant characteristics. Adjustment can address only measured confounders in a correctly specified and identifiable model; it does not make the study equivalent to a randomized trial [17,21]. Individual-level data are needed to verify adjusted effects, examine baseline knowledge, and assess the influence of PHC before stronger conclusions are drawn.

For practice, ANISA-based nutrition education and iron-tablet adherence monitoring may be considered for further supervised evaluation alongside routine antenatal care. This wording refers to the same ANISA package throughout the manuscript. The study does not yet establish effectiveness at scale. Important limitations include nonrandom allocation, unresolved PHC-by-group structure, possible site confounding, baseline knowledge and employment differences, differential adherence-recording methods, lack of participant masking, short follow-up, and absent iron-status biomarkers. A larger study with a clearly documented allocation process and an analysis appropriate to its clustering structure is needed.

CONCLUSION

Compared with leaflet-based education plus routine iron supplementation, ANISA-based nutrition education plus routine supplementation was associated descriptively with a larger increase in hemoglobin concentration, lower follow-up anemia prevalence, and higher adherence to prescribed iron tablets. Both groups improved in anemia-prevention knowledge, but greater knowledge improvement with ANISA was not demonstrated. The reported adjusted estimates require verification of the allocation and analysis before the magnitude of an intervention association can be confirmed. These findings support further evaluation rather than a definitive causal claim.

Primary healthcare services may consider a monitored pilot of the ANISA package as an adjunct to routine antenatal education and iron supplementation. Further research should document the intervention and comparison in reproducible detail, use an appropriate allocation and analysis strategy, measure iron status where feasible, apply comparable adherence assessment in both groups, and include longer-term maternal and neonatal outcomes.

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