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Effects of Iron Supplementation and Nutrition Education on Adolescent Girls' Knowledge, Adherence, and Hemoglobin Levels

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ABSTRACT

Anemia remains a major public health problem among adolescent girls in Indonesia. The effectiveness of iron supplementation programs is often constrained by inadequate knowledge and poor adherence to iron tablet consumption. This study analyzed the effects of iron supplementation integrated with nutrition education on knowledge, adherence, and hemoglobin (Hb) levels among adolescent girls. A quasi-experimental pretest-posttest control group design was conducted among 56 adolescent girls from four senior high schools in Maros Regency, Indonesia, using multistage cluster random sampling, with two schools allocated to an intervention group (n = 27, iron supplementation plus nutrition education) and two schools to a control group (n = 29, iron supplementation only). Baseline knowledge scores did not differ significantly between groups ($p = 0.115$); adherence was not assessed at baseline, as it was a prospective outcome measured throughout the intervention using the DOS method. Data were analyzed using the Wilcoxon, Mann-Whitney, paired t-test, and ANCOVA, with baseline hemoglobin, dietary intake, nutritional status, and menstrual cycle as covariates. Knowledge increased significantly in the intervention group ($p < 0.001$), with significant between-group differences in knowledge ($p < 0.001$) and adherence (92.6% vs. 44.8%; $p = 0.002$). Mean Hb rose significantly in the intervention group, from 13.12 ± 1.78 to 14.15 ± 1.35 g/dL ($p = 0.011$). Adjusted Hb remained significantly higher in the intervention than control (13.86 vs. 12.90 g/dL; $F = 6.065$; $p = 0.017$). Integrating nutrition education into iron supplementation programs improved knowledge, adherence, and Hb levels, supporting incorporation into school-based anemia prevention efforts.

INTRODUCTION

Anemia remains one of the most significant nutritional and public health problems worldwide, particularly among adolescent girls. The World Health Organization (WHO) recognizes anemia as a major health concern affecting women of reproductive age and adolescents, especially in low- and middle-income countries.[1] Likewise, the United Nations Children's Fund (UNICEF) has reported that improvements in the nutritional status of adolescent girls have progressed slowly, with anemia and micronutrient deficiencies remaining highly prevalent due to inadequate dietary intake, limited access to health and nutrition services, and persistent social and economic inequalities.[2] During adolescence, anemia contributes to fatigue, impaired immunity, reduced cognitive performance, poor academic achievement, and decreased productivity. If left untreated, it may persist into pregnancy, increasing the risk of maternal complications and adverse outcomes for both mothers and future generations.[1]

In Indonesia, anemia among adolescents remains a major public health challenge. National survey data indicate that the prevalence of anemia among individuals aged 15-24 years increased from 11.7% in 2007 to 21.7% in 2013 and 23.7% in 2018, before declining to 15.5% in the 2023 Indonesian Health Survey (SKI).[3] Although this trend indicates gradual improvement, the prevalence remains high and requires sustained prevention efforts. In South Sulawesi Province, anemia prevalence was reported at 11.4%.[3] Since 2014, the Indonesian government has implemented a nationwide weekly iron supplementation program for adolescent girls through the School Health Program (Usaha Kesehatan Sekolah/UKS), integrating iron tablet supplementation, nutrition education, and routine anemia screening.[4]

However, national and provincial figures are aggregate estimates that do not necessarily reflect conditions at the district or subdistrict level, given variation in program implementation quality across regions. Program-level evaluation data documenting how weekly iron supplementation coverage and adherence in Maros Regency evolved between the 2023 SKI reporting period and the present study are limited, making it difficult to determine whether local implementation has kept pace with the national downward trend. To provide a more specific picture of the current situation in the study area, secondary data from the Turikale Primary Health Center covering the most recent screening cycle (2025) were examined, showing that 172 of 338 screened adolescent girls (50.89%) were anemic-a prevalence markedly higher than the national and provincial figures reported in 2023. This substantial local-national discrepancy suggests that, despite continued national program rollout, translation into effective outcomes at the community level in this district may not have kept pace, underscoring the need for locally grounded evaluation rather than reliance on national trends alone. Previous studies have similarly reported that implementation of weekly iron supplementation programs remains inconsistent in several regions, characterized by limited coverage, irregular supervised consumption, and suboptimal adherence among adolescent girls.[5]

Poor adherence to weekly iron tablet consumption is influenced by multiple behavioral, educational, and environmental factors. Helmyati et al. reported that inadequate knowledge, low motivation, and limited parental and school support significantly influence adolescents' acceptance of iron supplementation programs.[5] Similarly, a local study in Turikale found that knowledge of anemia was significantly associated with adherence to weekly iron tablet consumption among adolescent girls.[23] According to the Theory of Planned Behavior, health-related behaviors are determined by attitudes, subjective norms, and perceived behavioral control.[6] However, many adolescents still demonstrate limited understanding of anemia and face difficulties maintaining consistent preventive behaviors, particularly when health education is delivered through conventional, lecture-based approaches that do not actively engage learners.

Conventional health education methods, such as one-time lectures, leaflets, and brochures, typically present information in a static, one-directional format that requires learners to passively absorb content without opportunities for elaboration or application. From a cognitive perspective, such passive delivery imposes high extraneous cognitive load-the mental effort expended on processing how information is presented rather than on understanding it-leaving fewer cognitive resources available for germane load, the effortful processing needed to build durable knowledge structures.[24] This may explain why conventional approaches often fail to produce lasting improvements in anemia-related knowledge among adolescent girls, as reported in previous reviews.[7]

The Active, Creative, Effective, and Joyful Learning (PAKEM) approach has been identified as an effective alternative, as it emphasizes participatory learning, active discussion, reflection, problem-solving, and the use of supportive learning media.[7] By requiring learners to actively engage with, elaborate on, and apply information rather than simply receive it, PAKEM is theorized to reduce extraneous cognitive load and redirect cognitive resources toward germane processing, thereby facilitating more meaningful and durable knowledge construction, consistent with Cognitive Load Theory.[24] This mechanism offers a plausible explanation for why interactive, PAKEM-based approaches have shown more consistent improvements in anemia-related knowledge compared with passive, lecture-based methods.[7,8]

Building upon this evidence, the present study developed a structured nutrition education intervention combining PAKEM-based interactive learning, spaced repetition to strengthen long-term retention, and Directly Observed Supplementation (DOS) to ensure supervised weekly iron tablet consumption. These three components were designed to complement one another. PAKEM-based education was intended to build and consolidate knowledge, spaced repetition to reinforce knowledge throughout the four-week intervention period, and DOS to promote consistent adherence to IFA tablet consumption, thereby supporting greater improvements in hemoglobin levels than IFA supplementation alone.

Although previous studies have demonstrated the benefits of nutrition education or iron supplementation individually, most have focused on single outcomes such as knowledge or adherence, without simultaneously evaluating biological outcomes such as hemoglobin levels. Moreover, evidence regarding interventions that combine interactive education, repeated reinforcement, and supervised supplementation remains limited, particularly in South Sulawesi. Therefore, this study aimed to analyze the effects of iron supplementation combined with structured nutrition education on anemia-related knowledge, adherence to weekly iron tablet consumption, and hemoglobin levels among adolescent girls in Turikale District, Maros Regency. We hypothesized that integrating PAKEM-adapted nutrition education, spaced repetition, and Directly Observed Supplementation (DOS) with iron supplementation would produce greater improvements in knowledge, adherence, and hemoglobin levels than iron supplementation alone, reflecting the expected synergistic contribution of educational reinforcement and supervised supplementation (H1), whereas the null hypothesis (H0) assumed no significant differences between the intervention and control groups.

MATERIALS AND METHODS

This study employed a quasi-experimental design with a pretest-posttest non-equivalent control group approach to evaluate the effects of iron supplementation and structured nutrition education adapted from PAKEM (Active, Creative, Effective, and Joyful Learning) principles, incorporating spaced repetition, on knowledge, adherence to IFA tablet consumption, and hemoglobin (Hb) levels among adolescent girls. A non-equivalent, non-randomized control group design was selected because random assignment of individual students was not feasible within a school-based setting. Instead, comparability between the intervention and control groups was pursued through baseline matching on age, nutritional status (BMI-for-age), and menstrual cycle regularity, with any remaining imbalance in these characteristics subsequently controlled for statistically using ANCOVA.

This study was conducted in Turikale District, Maros Regency, South Sulawesi, Indonesia. The overall study period, from March to May 2026, encompassed ethical approval procurement and field preparation in addition to the primary data collection phase. Primary data collection itself spanned seven consecutive weeks. In Week 1, school and participant screening was conducted, along with baseline matching of intervention and control groups on age, nutritional status (BMI-for-age), and menstrual cycle regularity. In Week 2, baseline (pretest) assessment of hemoglobin and anemia knowledge was administered to all participants in both groups. The four-week intervention then followed from Week 3 to Week 6: in Week 3, intervention group participants received a structured, PAKEM-adapted educational session, while all participants in both groups received the first weekly IFA tablet dose via Directly Observed Supplementation (DOS); in Weeks 4 through 6, intervention group participants received weekly reinforcement educational posters as a spaced-repetition strategy, while both groups continued receiving weekly DOS-supervised IFA tablet doses. Throughout Weeks 3-6, intervention group participants also maintained a reflective diary recording IFA consumption and related experiences, while control group participants received iron supplementation only, without educational materials, posters, or diaries. Finally, in Week 7, one week after intervention completion, posttest assessment of hemoglobin and anemia knowledge was conducted for all participants using the same instruments and procedures as at baseline.

The study population comprised all female students in grades X and XI across 16 schools in

Turikale District, Maros Regency. A total of 56 participants were selected using a multistage cluster random sampling technique, in which four schools were randomly selected as clusters and subsequently allocated into an intervention group (two schools: SMA IT Al-Islah and MAS Darul Muttaqin; n = 27) and a control group (two schools: SMAS Qurratu A'yun and SMA DDI Aliritengae Maros; n = 29).

Inclusion criteria were female students in grades X and XI who had experienced menstruation, were not receiving concurrent iron or hormonal supplementation, provided written informed consent, were not participating in other interventions, and were in good general health. Exclusion criteria included heavy menstrual bleeding, incomplete pretest or posttest measurements, and chronic diseases affecting hemoglobin levels, such as thalassemia, hemolytic anemia, and chronic kidney disease.

Prior to the intervention, a screening and matching process was conducted to ensure comparability of baseline characteristics-including age, menstrual cycle regularity, and nutritional status (BMI-for-age)-between the intervention and control groups, given the non-randomized nature of the design. Where imbalance in baseline characteristics could not be fully addressed through matching, the relevant variables were treated as covariates and controlled for using ANCOVA.

This study examined one independent variable, three dependent variables, and four covariates. The independent variable was iron supplementation integrated with structured nutrition education adapted from PAKEM, incorporating spaced repetition, operationalized as group allocation (intervention vs. control). The dependent variables were anemia knowledge, adherence to IFA tablet consumption, and hemoglobin level. Anemia knowledge and hemoglobin level were measured at baseline (pretest) and following the four-week intervention (posttest), whereas adherence was measured prospectively throughout the four-week intervention period, as this behavioral outcome could only be observed once IFA tablet distribution began.

The covariates-included in the ANCOVA model to statistically control for baseline imbalance not fully addressed through matching-were baseline hemoglobin level, nutritional status (BMI-for-age), dietary intake (protein, iron, and vitamin C), and menstrual cycle.

Data were collected using an anemia knowledge questionnaire, a respondent characteristics form, two non-consecutive 24-hour dietary recalls (to assess protein, iron, and vitamin C intake), IFA tablet consumption diaries, and adherence monitoring sheets. The anemia knowledge questionnaire was adopted from a previous study[25] and consisted of 15 multiple-choice items, each scored 1 for a correct answer and 0 for an incorrect answer, yielding a maximum total score of 15. Item validity had been established in the original study through item-total correlation analysis, with all 15 items demonstrating significant correlations with the total score; reliability testing yielded a Cronbach's alpha of 0.916, indicating excellent internal consistency. The questionnaire was therefore used in this study without re-testing its validity and reliability. Hemoglobin was measured using an EasyTouch GCHb device. Nutritional status was assessed using BMI-for-age. Adherence was monitored using the Directly Observed Supplementation (DOS) method.

Given the nature of the intervention, blinding of participants to group allocation was not feasible, as participation in the educational sessions was inherently apparent to those involved. Blinding of field enumerators and the data analyst was likewise not applied, as data collection, entry, and statistical analysis were all conducted by the principal investigator, who was also responsible for delivering the intervention. This absence of blinding at both the data collection and analysis stages is acknowledged as a methodological limitation and is discussed further in the Discussion section, where independent, blinded outcome assessment and analysis are recommended for future studies.

Data were analyzed using SPSS software. Descriptive statistics included frequency, percentage, mean, and standard deviation. Normality of data distribution was assessed using the Shapiro-Wilk test prior to hypothesis testing. Variables with normally distributed data were analyzed using parametric tests, including the paired t-test for within-group comparisons of hemoglobin levels, whereas variables with non-normally distributed data were analyzed using non-parametric equivalents, including the Wilcoxon Signed-Rank Test for within-group comparisons of knowledge scores. Between-group comparisons were analyzed using the Mann-Whitney U Test. ANCOVA was used to control for covariates. Statistical significance was set at $p < 0.05$.

Ethical approval was obtained from the Health Research Ethics Committee of Universitas Muslim Indonesia under approval number 322A/.1/KEP-UMI/IV/2026. Written informed consent was obtained from all participants and their parents/guardians prior to data collection.

RESULTS

Table 1. Characteristics of respondents

Variable	Intervention (n=27)		Control (n=29)	
	n	%	n	%
Age (years)				
15-16	15	55.6	11	37.9
17-18	12	44.4	18	62.1
Nutritional status (BMI-for-age)				
Underweight	3	11.1	2	6.9
Normal	18	66.7	23	79.3
Overweight	3	11.1	2	6.9
Obesity	3	11.1	2	6.9
Menstrual cycle				
Normal	20	74.1	20	69

Abnormal	7	25.9	9	31

Source: Primary Data, 2026

This study involved adolescent girls divided into intervention and control groups. In the intervention group, the majority of respondents were aged 15-16 years (55.6%), whereas most participants in the control group were aged 17-18 years (62.1%). Most respondents in both groups had normal BMI-for-age (66.7% in the intervention group and 79.3% in the control group), and most participants reported a normal menstrual cycle (74.1% and 69.0%, respectively).

The Shapiro-Wilk test showed that knowledge scores were not normally distributed in one of the study groups ($p < 0.05$); therefore, within-group comparisons were analyzed using the Wilcoxon Signed-Rank Test. Adherence data were also not normally distributed in both groups ($p < 0.05$), and between-group comparisons were analyzed using the Mann-Whitney U Test. In contrast, hemoglobin levels were normally distributed in both groups ($p > 0.05$), allowing within-group comparisons to be analyzed using the paired t-test.

Table 2. Effect of Iron Supplementation and Nutrition Education on Anemia Knowledge among Adolescent Girls

Group	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	*p*-value (within)*	*Mean Rank*	*p-value (between)**
Intervention	63.45 ± 16.97	88.89 ± 8.86	0.000	38.98	p < 0.001
Control	70.34 ± 15.18	71.26 ± 13.82	0.623	18.74	

*Wilcoxon signed rank test; Mann-Whitney U Test; significant at $p < 0.05$

Source: Primary Data, 2026

Based on Table 2, the intervention group showed a substantial increase in mean knowledge score from 63.45 ± 16.97 at pretest to 88.89 ± 8.86 at posttest, with the Wilcoxon Signed-Rank Test confirming this change as statistically significant ($p < 0.001$). In contrast, the control group showed only a marginal change in mean knowledge score, from 70.34 ± 15.18 to 71.26 ± 13.82, which was not statistically significant ($p = 0.623$). The Mann-Whitney U Test revealed a significant difference in knowledge scores between the two groups ($p < 0.001$), with the intervention group obtaining a higher mean rank (38.98) compared to the control group (18.74). These findings indicate that iron supplementation combined with nutrition education was more effective in improving adolescent girls' knowledge of anemia than iron supplementation alone.

Table 3. Effect of Iron Supplementation and Nutrition Education on Adherence to Iron Tablet (IFA) Consumption among Adolescent Girls

Adherence Category	Intervention (n = 27) (%)	Control (n = 29) (%)	Mean Rank (Intervention)	Mean Rank (Control)	U	Z	p-value*
Adherent	25 (92.6)	13 (44.8)					
Non-adherent	2 (7.4)	16 (55.2)					

Mann-Whitney U test	35.20	22.26	210.500	−3.102	0.002

*Mann-Whitney U Test; significant at p < 0.05.

Source: Primary Data, 2026

Based on Table 3, 25 of 27 participants (92.6%) in the intervention group were adherent to iron tablet (IFA) consumption, compared with 13 of 29 participants (44.8%) in the control group. The Mann-Whitney U test demonstrated a significant difference in adherence between the two groups (U = 210.500, Z = −3.102, p = 0.002), with a higher mean rank observed in the intervention group (35.20) than in the control group (22.26). These findings indicate that iron supplementation combined with nutrition education was more effective in improving adherence to iron tablet consumption than iron supplementation alone.

Table 4. Effect of Iron Supplementation and Nutrition Education on Hemoglobin Levels Among Adolescent Girls

Group	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	*p*-value*
Intervention	13.12 ± 1.78	14.15 ± 1.35	0.011
Control	12.34 ± 1.64	12.63 ± 1.38	0.271

*Paired Samples t-Test; significant at p < 0.05

Source: Primary Data, 2026

Based on Table 4, the paired t-test showed a significant increase in hemoglobin (Hb) levels in the intervention group, from 13.12 ± 1.78 g/dL at pretest to 14.15 ± 1.35 g/dL at posttest (p = 0.011). In contrast, the control group showed only a slight increase in Hb levels, from 12.34 ± 1.64 g/dL to 12.63 ± 1.38 g/dL, which was not statistically significant (p = 0.271). These findings indicate that a statistically significant improvement in Hb levels occurred only in the intervention group.

Table 5. Effect of Iron Supplementation and Nutrition Education on Post-Intervention Hemoglobin Levels After Adjusting for Covariates

Source	Adjusted Mean Hb (g/dL)	df	F	p-value	Partial Eta Squared
Intervention	13.859	1	6.065	0.017*	0.112
Control	12.904				
Baseline hemoglobin		1	7.370	0.009	0.133
Menstrual cycle		1	0.278	0.601	0.006
Nutritional status		1	0.151	0.699	0.003
Vitamin C intake		1	0.771	0.384	0.016
Iron intake		1	1.185	0.282	0.024
Protein intake		1	0.562	0.457	0.012
Error		48			

*Analysis of Covariance (ANCOVA); significant at p < 0.05.

Source: Primary Data, 2026

Based on Table 5, after adjusting for baseline hemoglobin, menstrual cycle, nutritional status, vitamin C intake, iron intake, and protein intake, the ANCOVA results showed that the intervention group had a significantly higher adjusted mean post-intervention hemoglobin level (13.859 g/dL) than the control group (12.904 g/dL). The intervention remained a significant predictor of post-intervention hemoglobin levels ($F(1,48) = 6.065$, $p = 0.017$, partial $\eta^2 = 0.112$). Among the covariates, only baseline hemoglobin was significantly associated with post-intervention hemoglobin levels ($F(1,48) = 7.370$, $p = 0.009$), whereas menstrual cycle, nutritional status, vitamin C intake, iron intake, and protein intake were not statistically significant (all $p > 0.05$). The partial eta squared value indicates that the intervention explained 11.2% of the variance in post-intervention hemoglobin levels after adjustment for the covariates. These findings indicate that the beneficial effect of the intervention on hemoglobin levels remained significant after controlling for potential confounding variables.

DISCUSSION

Characteristics of Respondents

The intervention group was predominantly aged 15-16 years, whereas the control group was predominantly aged 17-18 years. Both groups represented mid-to-late adolescence, a period characterized by rapid growth and increased iron requirements.[3] According to the Kementerian Kesehatan Republik Indonesia (2023), adolescence is a critical growth period associated with increased nutritional needs, particularly iron. Consistently, the World Health Organization states that adolescent girls are at higher risk of anemia due to increased iron requirements during growth and menstruation.[1] Age has also been identified as a factor associated with anemia among adolescent girls aged 15-24 years.[9] This confirms that both groups in the present study belonged to a vulnerable population and were appropriate targets for anemia prevention through nutrition education and iron-folic acid (IFA) tablet supplementation.

In addition to age, other characteristics such as nutritional status and menstrual cycle should also be considered, as both are associated with the risk of anemia among adolescent girls. Most respondents had normal nutritional status and comparable menstrual cycle patterns between groups, indicating a relatively homogeneous baseline condition. Previous studies have shown that irregular menstrual cycles may increase the risk of anemia through greater iron loss,[10] while nutritional status has also been identified as a significant determinant of anemia risk among adolescent girls.[11]

Effect of Iron Supplementation and Nutrition Education on Knowledge

The Wilcoxon Signed-Rank Test showed a significant increase in knowledge scores in the intervention group ($p = 0.000$), while no significant change was observed in the control group ($p = 0.623$). The Mann-Whitney U Test further confirmed a significant difference in knowledge scores between groups (p = 0.000), with the intervention group obtaining a higher mean rank. These findings support rejection of the null hypothesis and indicate that iron supplementation combined with structured nutrition education had a significant effect on adolescent girls' knowledge of anemia.

The substantial improvement in the intervention group can be attributed to the characteristics of the PAKEM (Active, Creative, Effective, and Joyful Learning) approach adapted in this study, which integrated interactive group discussions and visual media such as posters and presentation materials. This active engagement is thought to facilitate deeper understanding, as information is not merely received passively but is processed through discussion and reflection.[8] This is consistent with a systematic review and meta-analysis showing that although conventional educational methods such as leaflets and brochures do not consistently improve anemia-related knowledge, more interactive and participatory approaches adapted from PAKEM produce a more meaningful impact on adolescent girls' knowledge.[7,8]

The effectiveness of the intervention was further reinforced by the combination of spaced repetition and active recall applied consistently throughout the weekly education sessions. Spaced repetition, delivered through periodic reinforcement of material, aligns with the Ebbinghaus forgetting curve, which demonstrates that information is rapidly forgotten unless reinforced at intervals. At each session, short quizzes were also administered as a form of active recall, a strategy shown to strengthen memory retention more effectively than passive re-reading; spaced repetition embedded in structured learning has been shown to significantly improve knowledge retention and learner engagement compared to conventional methods.[12]

In contrast, the control group, which received IFA supplementation without structured education, did not show a significant improvement in knowledge. This suggests that knowledge of anemia does not develop automatically through supplementation alone but requires active and repeated learning stimulation. Without systematic educational exposure, understanding of anemia, the benefits of IFA tablets, and correct consumption practices tends to remain stagnant, consistent with previous findings that education lacking active and participatory methods tends not to produce meaningful changes in adolescent girls' knowledge.[7] This finding reinforces that tablet distribution alone is insufficient to improve health literacy related to anemia.

The improvement in knowledge achieved by the intervention group has relevant implications for IFA consumption adherence and anemia prevention efforts overall, as adolescent girls with better understanding of the impact of anemia and the benefits of IFA tend to be more motivated to consume the tablets regularly, with structured education on iron tablets shown to improve knowledge as a foundation for better consumption behavior. Overall, these findings indicate that structured, participatory, and repeated nutrition education adapted from PAKEM is more effective in improving anemia-related knowledge than supplementation alone, and that this knowledge gain serves as an important foundation for adherence and sustainable anemia prevention behavior among adolescent girls.[8]

Effect of Iron Supplementation and Nutrition Education on IFA Consumption Adherence

The Mann-Whitney U Test revealed a significant difference in IFA consumption adherence between groups (p = 0.002), with the intervention group obtaining a substantially higher mean rank than the control group. This finding supports rejection of the null hypothesis, indicating that the combination of iron supplementation and structured nutrition education significantly improved IFA consumption adherence compared to supplementation alone.

This difference can be explained through the PRECEDE-PROCEED model, which posits that health behavior is influenced by predisposing, enabling, and reinforcing factors.[14,26] Reflecting the continued relevance of this framework, a recent editorial interview with the model's original author reaffirmed that PRECEDE-PROCEED has been progressively refined to incorporate policy, environmental, and evaluation dimensions alongside its original educational-diagnostic constructs, underscoring its ongoing applicability to contemporary school-based health interventions.[26] In this study, the knowledge gained through structured and repeated education sessions functioned as a predisposing factor that shaped positive attitudes toward IFA consumption, ultimately encouraging consistent adherent behavior. This finding is consistent with a previous study conducted among adolescent girls in the working area of the Turikale Primary Health Center, which reported a significant association between anemia knowledge and adherence to IFA tablet consumption, indicating that better knowledge contributes to higher adherence to iron supplementation programs.[23] In addition, the Directly Observed Supplementation (DOS) approach applied in this study ensured that tablets were genuinely consumed under direct supervision, while also allowing continuous reinforcement of educational messages throughout the intervention period.[15]

However, adherence is not determined by knowledge alone. The Health Belief Model explains that perceived barriers are among the strongest determinants of health behavior; even when the benefits of an action are understood, an individual may not act if the perceived barriers outweigh the perceived benefits.[16] Common barriers to IFA consumption among adolescent girls include dislike of the tablet's smell and taste, experience of side effects, and misconceptions about IFA, whereas awareness of IFA benefits, trust in school programs, and support from parents and peers tend to promote adherence.[17]

Reflective diary entries from the intervention group support this explanation. Several respondents initially reported nausea, dizziness, and discomfort after consuming IFA tablets, which raised doubts about continuing consumption before they understood that such side effects are typically transient. Following education on the benefits of IFA and how to manage these side effects, most respondents continued consumption, and the reported discomfort gradually diminished in subsequent weeks. This shift was accompanied by a notable change in perception, as respondents who initially viewed IFA with apprehension came to recognize its benefits directly, consistent with findings that perceived susceptibility, severity, benefits, barriers, and self-efficacy are significantly associated with IFA consumption adherence among adolescent girls.[18]

Respondents in the intervention group also reported positive changes such as reduced drowsiness during lessons, improved concentration, and greater energy, which served as reinforcing factors that strengthened motivation to maintain regular IFA consumption. Other reinforcing factors included peer support, regular reminders during the study period, and a shared sense of accountability from consuming IFA tablets together as a group, alongside the enabling factor of guaranteed tablet availability throughout the intervention.

In contrast, the control group, which received IFA distribution without structured education, demonstrated lower adherence, reflected in its considerably lower mean rank. This is likely attributable to insufficient understanding of IFA benefits, unaddressed fear of side effects, and reduced motivation to continue consumption when discomfort was experienced, consistent with the Health Belief Model's premise that adherence is difficult to achieve when perceived barriers are not addressed through education.[16] Overall, these findings demonstrate that the combination of structured nutrition education adapted from PAKEM and the DOS approach significantly improved IFA consumption adherence, underscoring that successful supplementation programs depend not only on tablet availability but also on education that addresses perceived barriers, strengthens motivation, and builds supportive social environments.

Effect of Iron Supplementation and Nutrition Education on Hemoglobin Levels

The paired t-test showed a significant increase in Hb levels in the intervention group ($p = 0.011$), while no significant change was observed in the control group ($p = 0.271$). After controlling for covariates, the ANCOVA results confirmed a significantly higher adjusted mean Hb level in the intervention group compared to the control group ($F = 6.065$; $p = 0.017$; partial $\eta^2 = 0.112$). These findings support rejection of the null hypothesis, indicating that iron supplementation combined with structured nutrition education was more effective in improving Hb levels than supplementation alone. The increase in Hb levels in the intervention group can be explained through the physiological role of iron in erythropoiesis. Iron is a key component of hemoglobin, which binds oxygen for distribution throughout body tissues; under iron-deficient conditions, hemoglobin synthesis is impaired, reducing erythrocyte production and leading to iron-deficiency anemia.[13] Adolescent girls are particularly vulnerable to this condition due to increased iron requirements during rapid growth and periodic blood loss through menstruation. Regular IFA tablet consumption increases iron availability, supporting hemoglobin synthesis and erythrocyte formation in the bone marrow, with oral iron supplementation consistently shown to increase Hb levels among children and adolescents, particularly among those with lower baseline Hb.[19] An Hb increase of ≥1 g/dL at day 14 of oral iron therapy has been identified as an accurate predictor of long-term treatment success, with a sensitivity of 90.1% and specificity of 79.3%.[20] This is consistent with findings reported by a previous study among anemic adolescent girls, which observed a significant increase in Hb after four weeks of weekly IFA supplementation, with no meaningful change in the unsupplemented control group.[21]

Beyond supplementation, the improvement in Hb levels among the intervention group was also supported by structured nutrition education delivered throughout the four-week intervention, which enhanced respondents' understanding of anemia, the benefits of IFA tablets, and correct consumption practices to optimize iron absorption, including co-consumption with vitamin C sources and avoidance of tea or coffee containing tannins. This improved understanding contributed to better IFA adherence, ensuring more adequate and consistent iron intake, consistent with previous findings that comprehensive nutrition education improves both knowledge and adherence to IFA tablet consumption among adolescent girls, ultimately contributing to meaningful improvements in Hb levels.[8] The intervention's effectiveness was further reinforced by the DOS approach, whereby direct supervision of IFA tablet consumption significantly improves adherence compared with unsupervised distribution, thereby maximizing the effect of supplementation on Hb levels.[15]

The ANCOVA results further indicated that baseline Hb level was a significant covariate contributing to posttest Hb levels, suggesting that individuals with lower baseline Hb levels generally have more limited iron reserves and therefore demonstrate a greater response to supplementation, whereas those with Hb levels closer to the normal range tend to show a more limited increase due to relatively lower erythropoietic demand; this is consistent with a meta-analysis confirming baseline hemoglobin as one of the strongest predictors of response to iron supplementation among children and adolescents.[19] Other covariates, including protein, iron, and vitamin C intake, menstrual cycle, and nutritional status, did not show a significant contribution in the ANCOVA model, which may reflect limited variation in dietary intake among respondents rather than the absence of a true physiological effect, as well as limitations of the 24-hour dietary recall method in capturing long-term consumption patterns.[22]

Overall, these findings indicate that the improvement in Hb levels observed in the intervention group resulted from the combined effects of IFA supplementation, which provided the iron substrate required for erythropoiesis, nutrition education adapted from PAKEM, which improved knowledge and adherence, and the DOS approach, which ensured consistent IFA tablet consumption. These results reinforce the importance of integrating IFA supplementation, comprehensive nutrition education, and adherence monitoring as a sustainable and integrated strategy for anemia prevention among adolescent girls.

Methodological Considerations

Several methodological considerations should be noted when interpreting these findings. First, blinding of participants, field enumerators, and the data analyst was not feasible, as the principal investigator was responsible for delivering the intervention, collecting outcome data, and conducting the statistical analysis; this may introduce measurement or analysis bias and is recommended to be addressed through independent, blinded personnel in future studies. Second, normality testing indicated a borderline deviation for hemoglobin at baseline in the intervention group; nonetheless, parametric analysis was retained given its robustness to minor deviations from normality, and this consideration should be taken into account when interpreting the magnitude of the reported effect. Third, dietary intake was assessed using only two non-consecutive 24-hour recalls and treated solely as a covariate rather than a primary variable; this approach may not fully capture habitual consumption patterns, and future studies should consider more representative methods such as semi-quantitative food frequency questionnaires (SQ-FFQ) or multi-day food records, alongside other potentially influential factors such as stress, sleep quality, and physical activity that were not assessed in the present study.

CONCLUSION

This study demonstrates that iron-folic acid (IFA) supplementation integrated with structured nutrition education adapted from PAKEM (Active, Creative, Effective, and Joyful Learning) principles, incorporating spaced repetition and Directly Observed Supplementation, was more effective than IFA supplementation alone in improving anemia-related knowledge, adherence to IFA consumption, and hemoglobin levels among adolescent girls. These findings support the directional hypothesis that combining educational reinforcement with supervised supplementation produces synergistic rather than merely additive benefits, providing empirical grounding for strengthening school-based anemia prevention strategies in similar settings.

For practical implementation, school health units (UKS) are recommended to adopt a structured, three-component protocol that can be embedded within existing UKS scheduling infrastructure rather than introduced as a separate program: (1) training designated UKS teachers or student health cadres to deliver a single PAKEM-adapted educational session at the start of each IFA supplementation cycle, using low-cost, reusable discussion guides and posters; (2) scheduling brief, weekly poster-based reinforcement aligned with the existing weekly IFA distribution calendar, requiring no additional school visits; and (3) formalizing supervised tablet consumption (DOS) as a routine responsibility of homeroom teachers or trained peer monitors, supported by simple, low-burden adherence-tracking sheets. This integration offers a feasible pathway to scale the approach across schools with limited additional resources, directly addressing the coverage and adherence gaps identified in local program evaluation.

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