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Effect of optimized food-based recommendations on nutrient intakes, hemoglobin levels, and memory performance of adolescent girls in East Java, Indonesia

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Abstract

Background FAO/WHO introduced food-based dietary guidelines (FBDG) to promote healthy dietary habits. To translate the FBDG, optimized food-based recommendations (FBR) can be developed using linear programming (LP) to address problem nutrients. Despite the importance of local-specific FBR for anemia prevention, no study has reported the effect of nutrition education which promoted FBR in adolescent girls. Therefore, this study aimed to investigate the effect of optimized FBR in adolescent girls in improving dietary and nutrient intakes, hemoglobin levels, and memory performance.

Methods The intervention study was carried out in Malang District, Indonesia amongst 14–18 year adolescent girls. The study's Indonesian slogan was Remaja which meant Active, Healthy, Smart, and Creative adolescents. The optimized FBR was developed using LP and translated into six key messages. Twenty-week nutrition education was integrated into the weekly school's system.

Results After 20 weeks, a significant increase in dietary practices (animal protein, liver, plant protein, vegetables), nutrient intakes (protein, fat, iron), and memory performance (digit span forward and backward) were found in the intervention group. In contrast, there was decreases in the control group's intakes of animal and plant protein.

Conclusions This finding shows that nutrition education with optimized FBR increased intakes of nutrient-dense food, protein, fat, iron, and memory performance (concentration). Nutrition education with optimized FBR should be integrated into the school system together with weekly iron supplementation for anemia prevention among these adolescent girls.

Trial registration The study was registered on ClinicalTrials.gov (ID No: NCT03946475).

Keywords Adolescent girls, Anemia, Food-based recommendations, Linear programming, Memory performance, School-based nutrition education

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Background

Evidence based on the field of Developmental Origins of Health and Disease (DOHad), indicates that early-life environmental exposures impact the later-life risk of non-communicable diseases (NCDs) [1, 2]. Although many studies reported that pregnancy, lactation, and early childhood were the critical windows of opportunity for nutrition intervention [3, 4], adolescence as the preconception period was still overlooked to capture the full potential of DOHaD. Adolescents are in the process of establishing their health-related behaviors, including diet [5]. Consequently, these behaviors will influence their health before conception and contribute to NCD risks in offspring [6].

The Food and Agriculture Organization of the United Nations and the World Health Organization recommended Food-Based Dietary Guidelines (FBDG) to establish healthy dietary behaviours [7]. The linear programming (LP) approach could be used to formulate food-based recommendations (FBR) to further translate the FBDG to address specific problem nutrients of the target group and simultaneously align with local food availability, affordability, and acceptability [8]. This approach has been used in developing countries [9–11] to develop FBR for intervention studies in under-two children [11]. However, none of the intervention studies with FBR developed using LP was conducted in adolescent girls.

In Indonesia, three intervention approaches to tackle nutritional anemia have been implemented, namely food-based intervention, iron-folic acid supplementation, and nutrition education in adolescent girls [12]. Previous studies have reported effect of school-based nutrition education in improving nutrition knowledge [13, 14], dietary intake [15], hemoglobin level [14–17], and dietary behaviors [18–23], but no study reported effect of nutrition education, especially which promoted FBRs, in improving cognition in adolescent girls. Therefore in this study we aimed to assess the effect of nutrition education which promoted optimized FBR developed using LP in improving comprehensive indicators including dietary and nutrient intakes, hemoglobin levels, and memory performance in adolescent girls.

Methods

Study design and setting

An intervention study with control as a comparison was conducted in Malang District, East Java, Indonesia in collaboration with the District Education Office and District Health Office of Malang District, East Java Province. The intervention sessions were implemented over 20 weeks. Baseline data collection was performed in October 2016 and endline data collection in May 2017.

Sample size and selection

The following formula [24] conducted sample size calculation for a two-arm trial with equal allocation, which was calculated as:

$$m = \frac{(Z_{1-\alpha/2} + Z_{1-\beta})^2 \, 2\sigma^2}{\Delta^2} \, (1 + (n-1)\rho$$

$n = 30$ (The number of individuals per cluster).
p = 0.017 (Internal class correlation) [25].
m = The number of individuals per group.
$Z_{1-\alpha/2} = 1.96$ (Level of significance 5%).
$Z_{1-\beta} = 0.842$ (Power of the test 80%).
σ^2 = Variance [26] = 0.212.
Δ = Mean difference [26] = 0.036.

In brief, the calculation resulted in 152 respondents per group or 304 respondents for the total sample in this study. However, assuming a drop-out, the number of participants was increased to 160 per group. Respondents were mixed between normal and anemic (mild and moderate) adolescent girls for both intervention and control groups.

Group allocation

The total respondents ($n = 323$) were recruited from eight schools (40 adolescent girls per school). Out of 66 schools in Malang District, eight schools were selected based on the following inclusion criteria: (1) Not boarding schools, and (2) Having a large number of students. These eight schools covered six sub-districts in Malang District.

Previously, we conducted a preliminary study investigating problem nutrients among adolescent girls in two schools in Malang District [27]. Therefore, we assigned these two schools as the intervention group in this study. Then, the remaining intervention schools were based on the consideration: (1) The schools' cooperation both of chair and staff/teachers; (2) Prevalence of anemia in the baseline data collection; (3) Representativeness of district area. In some schools, adolescent girls from all grades (1st −3rd) were included, whereas, in others, only adolescent girls from certain grades participated in this study due to school approval.

We obtained a list of adolescent girls from the school and randomly assigned them using the Random Number app. The inclusion criteria of adolescent girls were: (1) 1st, 2nd, or 3rd year of senior high school; (2) Age 14–18 years; (3) Already menarche; and (4) Apparently healthy. In addition, the exclusion criteria were: (1) Severely anemic (< 80 mg/dL); (2) Having serious illness (e.g. chronic kidney disease, tuberculosis). The final total sample consisted of 323 respondents in the baseline data. However, 17 respondents were lost to follow-up in the endline data collection. In summary, 158 and 148 respondents were followed up in the intervention and control groups, respectively (5.3% dropout).

Intervention study

Prior to the intervention trial, formative research was conducted to determine the type of nutrition education that could be delivered in the school [27]. The "*Keputrian*" session was identified as the channel for nutrition education in the school. *Keputrian* is a weekly session to deliver religious information relevant to adolescent girls, usually held on Friday during Friday Prayer which is attended by the male students, and is part of the extracurricular. Therefore, we integrated the implementation of nutrition intervention into the Keputrian session, which was already part of the school's system.

In the study, the intervention group received "Remaja ASIK (Aktif, Sehat, pIntar, Kreatif)," the Indonesian tagline for nutrition education in the intervention schools which means "adolescent girls who are active, healthy, smart, and creative". Training of female teachers was conducted just before the rollout of nutrition education in the intervention group. At the beginning of the intervention, we promoted Remaja ASIK to parents so that families could support food availability to their daughters in accordance with the FBR messages.

Weekly nutrition education was performed every Friday, during the Keputrian session (30–50 min) over 20 weeks in the intervention group. In this study, female-trained teachers delivered the nutrition education messages in the Keputrian session. Supervisors, who were nutritionists, guided the teachers before they delivered messages to adolescent girls. The nutrition education consisted of lectures, posters, videos, booklets, and student-centered activities such as canteen observation, body mass index's calculation (BMI), and food label identification.

The information, education, and communication (IEC) materials were primarily delivered through student and teacher's modules. In the student's module, there were nutrition topics and task sheets. The teacher's module captured all topics consisting of the objective, summary, key messages, student's activities, teacher's guideline to deliver nutrition education, and evaluation of student's performance.

The module of Remaja ASIK covered 18 topics, including five cooking competitions to promote some nutrient-dense foods in optimized FBR. The delivered topics were (1) six key messages of optimized FBR, which included the recommended minimum portion/serving size (Table 1); (2) balanced nutrition; (3) anemia; (4) menstruation; (5) BMI; (6) healthy and smart adolescents; (7) strong bones; (8) healthy lunch boxes; (9) safe snacks, and (10) food labeling.

During the intervention, attendance to each session was recorded so that the adolescent girls who frequently missed the session could be identified. In the middle of the intervention (eighth week), a notification letter was sent to the parents whose children had < 70% attendance. At the end of the study, each school elected a Remaja

Table 1 Messages in the optimized food-based recommendations

1. Consume 3 meals and 2 snacks every day
2. Consume at least 2 portions/day of animal protein source foods, including at least 2 portions/week of liver
3. Consume at least 1 portion/day of tempeh or tofu
4. Consume 2 portions of vegetables/day, including at least 5 portions/week of green leafy vegetables
5. Consume at least 1 portion/day of fruits
6. Consume at least 3 portions/week of milk

Standard portion for the nutrient-dense foods promoted in the FBR

1 serving of animal protein	= 45g (cooked weight)
1 serving of liver	= 10g (cooked weight)
1 serving of soybean product	= 40g (fried weight)
1 serving of vegetables	= 80g (cooked weight)
1 serving of green leafy veg	= 35g (boiled weight)
1 serving of fruits	= 80g (edible wet weight)
1 serving of milk	= 80g (ready-to-drink milk)

ASIK ambassador responsible for promoting nutrition education to their colleagues. These adolescent school girls represented their schools at Remaja ASIK Festival to be the best ambassador in Malang District.

Data collection

We trained local enumerators in interviewing structured questionnaires, assessing dietary intake, and performing weight and height measurements before collecting data. In addition, the structured questionnaire was pretested in the field. Interview was conducted to obtain data on socioeconomic characteristics, dietary practices, and food consumption. Anthropometry assessment (weight and height), hemoglobin levels, and memory performance were also conducted.

The socioeconomic characteristics data included respondent's age, age at menarche, menstrual duration, daily pocket money, mother's education and occupation, living status, and school types.

Body weight was measured to the nearest 0.1 kg by SECA weight scale and height was measured to the nearest 0.1 cm by Shorr-board. Duplicate measurements were taken and the mean value was determined. The weight and height were then converted to BMI for age z-score (BAZ) by using WHO AnthroPlus software.

Dietary practices were assessed using a qualitative food frequency questionnaire (FFQ) to determine compliance with the six key messages of the optimized FBR per week and weekly frequency of consumption of specific foods promoted in the FBR (animal protein, liver, plant protein, vegetables, green leafy vegetables, fruits, and milk).

Individual food consumption was estimated using a 3-day-repeated-24-hour dietary recalls. We provided an Indonesian food picture book to estimate portion sizes of the respondent's consumption. The dietary data were then entered into Nutrisurvey software to estimate usual intake of protein, fat, calcium, iron, vitamin B12, folic acid, and vitamin A.

Hemoglobin levels were measured by a complete blood count analysis at an accredited laboratory in the Polyclinic of Brawijaya University. Anemia is defined as hemoglobin < 12 mg/dL [28].

Memory performance was measured as one of cognitive domains and administered by a well-trained enumerator who received training from a psychologist. Each measurement was performed using standardized test protocols (± 40 respondents for one hour) in the morning. This study measured concentration and memory among the adolescent school girls [29].

The digit span forward and backward from Wechsler Intelligence Scale for Children third edition (WISC-3) was used to evaluate concentration, short-term memory, and working memory capacity [30, 31]. The maximum number of digits used in the series is limited to seven. Strings of digits were read by the well-trained enumerator and the respondents were asked to memorize the number strings in forward and backward order [32].

The coding subtest from WISC-3 was employed to measure concentration and short-term memory [33, 34]. It was presented on a single sheet of paper with nine symbols paired with the number 1–9. The respondents were required to match symbols to numbers as accurately and quickly as possible within 120 s. A score of 1 is given for each correct answer. The maximum possible score is 144 [34].

The memory subtest form (the Intelligenz-Struktur-Test IST, the Indonesian version) was used to evaluate the memory. The respondents had three minutes to memorize words written on a piece of paper. Afterward, they had six minutes to finish twenty related-word phrases [35].

Data analysis

Data analysis was performed using R Studio version 4.1.2. Descriptive statistics, including means, median, 25th and 75th percentiles, standard deviations, percentages, and frequencies were used to describe the respondents' characteristics. We assessed the normality of continuous variables using the Kolgomorov-Smirnov test. The paired Wilcoxon test was used for the baseline and endline comparison of the study variables (continuous data) within the group. ANCOVA was used to assess the changes in hemoglobin levels and memory performance within groups using covariates. Statistical significance was set at $p < 0.05$.

Results

The final sample included 306 respondents (158 in intervention group and 148 in control group). Of these, only 270 respondents had complete baseline and endline measurements. The median age of the respondents was 16 years and age at menarche was 13 years. The majority of the respondents had normal BMI. The prevalence of anemia was low i.e. 6–7% (Table 2).

The majority of the adolescent girls in the intervention group had a longer menstrual duration and higher hemoglobin levels at baseline ($p < 0.05$). In addition, mothers in the intervention group had higher education levels than those in the control group at baseline ($p < 0.001$). More girls in the intervention group were attending public schools ($p < 0.001$). Despite these differences, age, age at menarche, BMI for age, anemia status, daily pocket money, mother's occupation, and living status were comparable between groups at baseline (Table 2).

As shown in Table 3, we found a significant difference in animal protein and milk consumption between

Table 2 Characteristics of adolescent girls in the intervention and control groups

Variables	Intervention ($n=145$)	Control ($n=125$)	*p*
Age[1]	16 (16, 16)	16 (16, 16)	0.321
Age at menarche[1]	13 (12, 13)	12 (12, 13)	0.600
Menstrual duration[1]	7 (5, 7)	6 (5, 7)	< 0.001*
Weight (kg)[1]	48.1 (42.0, 55.0)	49.7 (43.2, 55.2)	0.451
Height (cm) [2]	153.3 ± 6.01	153.3 ± 5.47	0.972
BMI for Age[3]			0.460
Thinnes	6 (4.1)	3 (2.4)	
Normal	111 (76.5)	103 (82.4)	
Overweight/obese	28 (19.3)	19 (15.2)	
Hemoglobin levels[2]	13.3 ± 1.1	13.6 ± 1.0	0.027*
Anemia status[3]			0.419
Mild anemia	8 (5.5)	7 (5.6)	
Moderate/severe anemia	2 (1.3)	0 (0)	
Pocket money (IDR 000/day)[1]	10 (10, 15)	10 (10, 15)	0.316
Mother's education[3]			< 0.001*
Low level	50 (34.5)	81 (65.3)	
Middle level	68 (46.9)	33 (26.6)	
High level	27 (18.6)	10 (8.1)	
Mother's occupation[3]			0.159
Formal	40 (27.6)	22 (17.7)	
Semi formal	26 (17.9)	26 (21.0)	
Not working	79 (54.5)	76 (61.3)	
Living with family: Yes[3]	130 (89.7)	108 (86.4)	0.524
School types[3]			< 0.001*
Public	111 (76.5)	62 (49.6)	
Private	34 (23.4)	63 (50.4)	

[1] Wilcoxon test, median (percentile 25, percentile 75)

[2] Independent t-test, mean ± SD

[3] Chi-square test, n (%)

*Significant difference if $p < 0.05$

groups at baseline ($p < 0.001$). However, the remaining food (liver, plant protein, vegetables, green leafy vegetables, and fruits) were comparable between groups at baseline. After receiving 20 weeks of nutrition education ($p < 0.001$), in the intervention group, there was a significant increase in animal protein, liver, plant protein, and vegetable consumption ($p < 0.05$).

At baseline, protein, and calcium intakes were higher in the intervention group ($p < 0.05$); however, intakes of fat, iron, vitamin B12, folic acid, and vitamin A were comparable with those in the control group. After the intervention study, there was a significant increase in protein, fat, calcium, vitamin B12, and folic acid intakes in the intervention group ($p < 0.01$). In contrast, in the control group, there was a significant decrease in intakes of protein, fat, calcium, B12, and folic acid ($p < 0.05$) and a borderline significant decrease in intakes of iron and vitamin A ($p < 0.1$) (Table 4).

Menstrual duration, mother's education levels, and baseline hemoglobin levels were used as covariates in the multiple regression analysis (Table 5). There was a significant decrease in hemoglobin levels after adjusting for menstrual duration in both groups after the intervention ($p < 0.001$). The memory performance tests were comparable at baseline, except for the coding test which was higher in the intervention group. After 20 weeks of intervention, the intervention group had a higher score in digit span forward compared to the control group ($p < 0.05$) and it also significantly increased from baseline ($p < 0.001$) after adjusting for mother's education levels and hemoglobin levels at baseline.

Discussion

This study aims to investigate the effect of optimized FBR in improving dietary and nutrient intakes, hemoglobin levels, and memory performance among adolescent girls after 20 weeks of intervention. The results showed that dietary practices and nutrient intakes in the intervention group significantly improved after receiving nutrition education for 20 weeks, while there was a significant decrease in the control group. Despite a decline in hemoglobin levels in both groups, both digit span forward and backward increased in the intervention group, while only the digit span backward increased in the control group.

The FBR promoted in Remaja ASIK was based on a previous study on LP approach [27]. The six key messages of optimized FBR were the dietary guidelines in adolescent girls through the promotion of nutrient-dense food subgroups and items, particularly those rich in iron, folate, vitamin A, and calcium, which are the identified problem nutrients in this study population [27]. In the current study, the increase in dietary practices of animal protein, liver, plant protein, and vegetables indicates that nutrition education had a positive effect on the establishment of good dietary practices in adolescent girls. The strength of the FBR developed using LP is that it is consistent with the existing dietary pattern and affordability. Therefore, it was easy to practice. Our 20 weeks of nutrition education promoting the local-specific FBR showed comparable results with previous studies in Southern Benin and Spain which had longer duration. In Southern Benin, a 26-week of nutrition education significantly improved dietary iron intake in adolescent girls [19]. In addition, a nutrition education conducted via three workshops in nine months delivered at schools was associated with a significant improvement in healthy eating habits among adolescents in Spain [21].

Table 3 Weekly frequency of consumption of food groups, food subgroups, or food items which were promoted in the optimized FBR before (baseline) and after (endline) the intervention

Outcome Variables	Intervention (n = 145)	Control (n = 125)	p [1]
Animal protein			
Baseline	13 (9, 18)	9 (6, 13)	< 0.001*
Endline	16 (11, 22)	8 (6, 13)	< 0.001*
p value within groups [2]	< 0.001*	0.944	
Liver			
Baseline	0 (0, 0)	0 (0, 0)	0.257
Endline	0 (0, 1)	0 (0, 0)	< 0.001*
p value within groups [2]	< 0.001*	0.499	
Plant protein			
Baseline	6 (3, 9)	6 (3, 9)	0.431
Endline	7 (4, 12)	5 (3, 7)	< 0.001*
p value within groups [2]	0.057*	0.221	
Vegetables			
Baseline	6 (3, 11)	6 (3, 9)	0.060
Endline	9 (6, 13)	6 (3, 8)	< 0.001*
p value within groups [2]	0.002*	0.392	
Green leafy vegetables			
Baseline	3 (2, 7)	3 (1, 5)	0.090
Endline	4 (2, 7)	3 (1, 5)	< 0.001*
p value within groups [2]	0.487	0.060	
Fruits			
Baseline	3 (2, 6)	2 (1, 4)	0.066
Endline	3 (2, 7)	3 (1, 4)	0.004*
p value within groups [2]	0.253	0.768	
Milk			
Baseline	3 (1, 7)	2 (1, 3)	< 0.001*
Endline	4 (2, 7)	1 (0, 3)	< 0.001*
p value within groups [2]	0.419	0.037*	

[1] Wilcoxon test (percentile 25, percentile 75)

[2] Paired Wilcoxon test

*Significant difference if $p < 0.05$

There is still insufficient studies on the effect of school-based nutrition intervention and cognitive performance, especially amongst adolescent girls. Creed-kanashiro et al. [18] conducted nutrition education for 9 months, however, this long period of intervention was not sufficient to improve hemoglobin levels significantly. In this study, there was a decrease in hemoglobin levels in both groups after 20 weeks even though improved dietary practices were seen in the intervention group. Decrease in hemoglobin levels despite increase in dietary intakes may be attributable to a higher menstrual duration (7 days) in the intervention group, which may have led to the imbalance between iron requirement and iron intake [28]. Furthermore, we did not use serum ferritin, an iron-specific biomarker. Based on Hallberg et al. [36], 10 mg/day of iron intake (assuming 10% bioavailability) is required to maintain Hb level at 13.4–13.6 mg/dL. In our study, the median iron intake of respondents was only 7.8–8.1 mg so it was insufficient to maintain hemoglobin levels. Therefore, to compensate for the gap in iron requirement (RNI 26 mg/day [37]), weekly iron-folic acid supplements (60 mg elemental iron and 350 µg folic acid) can be delivered to.

prevent anemia among respondents [27, 38]. A similar finding was also found from LP analysis to develop FBR for adolescent school girls in Vietnam [39].

In this study, memory performance measured concentration and memory. After 20 weeks of intervention, the most responsive test to short-term memory (digit span forward) in the intervention group increased after being

Table 4 Nutrient intakes of the adolescent girls before (baseline) and after (endline) the intervention

Outcome Variables	Intervention (*n* = 145)	Control (*n* = 125)	*p*
Protein (g)			
Baseline[1]	50.1 (44.0, 56.0)	45.1 (38.3, 52.9)	< 0.001*
Endline[2]	52.5 (43.3, 61.6)	40.8 (34.4, 50.2)	< 0.001*
p value within groups [3]	0.028*	0.005*	
Fat (g)			
Baseline[1]	56.0 (48.9, 63.7)	53.6 (43.6, 61.6)	0.110
Endline[2]	59.1 (50.6, 71.0)	49.8 (39.9, 60.8)	< 0.001*
p value within groups [3]	0.007*	0.040*	
Calcium (mg)			
Baseline[1]	358.2 (276.8, 465.3)	320.6 (274.3, 399.1)	0.026*
Endline[1]	366.3 (276.6, 467.4)	292.3 (228.0, 399.4)	< 0.001*
p value within groups [3]	0.666	0.017*	
Iron (mg)			
Baseline[1]	7.8 (6.4, 8.7)	7.9 (6.6, 10.0)	0.149
Endline[1]	8.1 (6.8, 9.9)	7.9 (5.8, 9.6)	0.154
p value within groups [3]	0.023*	0.099	
Vitamin B12 (mcg)			
Baseline[1]	2.6 (2.4, 3.5)	2.6 (1.8, 3.3)	0.052
Endline[1]	2.8 (2.1, 3.8)	2.3 (1.4, 3.0)	< 0.001*
p value within groups [3]	0.371	0.047*	
Folate (mcg)			
Baseline[1]	121.2 (98.9, 148.4)	140.7 (94.8, 161.1)	0.322
Endline[1]	116.5 (88.6, 163.4)	103.7 (81.1, 137.6)	0.017*
p value within groups [3]	0.864	< 0.001*	
Vitamin A (RE)			
Baseline[1]	899.5 (716.6, 1205.7)	1,092.7 (668.2, 1395.0)	0.324
Endline[1]	867.2 (621.6, 1233.0)	751.1 (698.9, 1221.5)	0.512
p value within groups [3]	0.497	0.062	

[1] Wilcoxon test, median (percentile 25, percentile 75)

[2] Independent t-test, mean ± SD

[3] Paired Wilcoxon test

*Significant difference if $p < 0.05$

Table 5 Hemoglobin levels and memory performance of the adolescent girls before (baseline) and after (endline) the intervention

Outcome Variables	Intervention (*n* = 145)	Control (*n* = 125)	*p*
Hemoglobin levels			
Baseline[1]	13.3 ± 1.1	13.6 ± 1.0	0.027*
Endline[2]	12.4 ± 1.0	12.7 ± 0.9	< 0.030*
p value within groups [2]	< 0.001*	< 0.001*	
Digit span forward (WISC-3)			
Baseline[1]	3.1 ± 0.9	3.1 ± 0.9	0.555
Endline[2]	3.6 ± 1.0	3.2 ± 0.9	0.002*
p value within groups [2]	< 0.001*	0.186	
Digit span backward (WISC-3)			
Baseline[1]	2.8 ± 1.2	2.7 ± 1.2	0.413
Endline[2]	3.3 ± 1.2	3.2 ± 1.2	0.608
p value within groups [2]	< 0.001*	< 0.001*	
Coding (WISC-3)			
Baseline[1]	71.1 ± 6.3	68.8 ± 8.0	0.013*
Endline[2]	70.1 ± 5.5	68.7 ± 8.9	0.040*
p value within groups [2]	0.571	0.976	
Memory test (IST)			
Baseline[1]	13.0 ± 4.3	12.8 ± 4.2	0.686
Endline[2]	13.8 ± 4.3	13.7 ± 4.4	0.956
p value within groups [2]	0.114	0.083	

[1] Independent sample t-test, mean ± SD

[2] ANCOVA covariates: (1) Hb: adjusted menstrual duration; (2) Digit span forward/backward/coding/memory test: adjusted by mother education level and baseline Hb

*Significant difference if $p < 0.05$

adjusted by covariates. The increased intakes of protein, calcium, iron, and vitamin B12 in the intervention group may affect concentration and short-term memory through the roles of calcium and water soluble vitamins in synthesizing brain neurotransmitters and maintaining neuron cell function [40]. Further analysis showed that the ratio between carbohydrate and protein intakes at baseline was 4:1 while it changed to 3:1 at endline. In addition, the intervention group consumed more animal protein and plant protein after receiving nutrition education. This finding is consistent with previous study [41] which demonstrated that protein-rich meal results in better short-term memory. The changes in memory functions were known to be associated with postprandial changes in glucose metabolism, GIR (glucagon to insulin ratio), and LNAA (large neutral amino acids) ratio.

After 20 weeks of intervention, significant increase in digit span backward and memory test (IST) was observed in both groups, but there was no significant between-group difference at baseline and endline. This finding is similar to Chung et al. [42] which found that the treatment group who received fortified grain and the control group had increased executive functioning measurements due to practice effects that continue to show up six or twelve months later) [43, 44].

Schools acting as the primary setting to promote health through the curriculum can contribute to improving dietary habits among children and adolescents. During the intervention of this study, nutrition education is not yet part of the school curriculum. Therefore, we used the Keputrian session which was attended by all adolescent girls but did not interrupt the student's learning schedule, and it was also supported by the school policy. Many school-based programmes demonstrated the important role of school policy, which focus on improving the school food environments [45]. School as a supportive environment can potentially affect student's future diet and disease risks in adulthood, thus it is necessary to improve school policies on nutrition and health. Nevertheless, meta-analysis studies also showed that, in addition to delivering the intervention in the school with the support of school policy, family support is needed to improve dietary habits [46, 47]. In Remaja ASIK intervention, we promoted the parents so they could provide the necessary support for their children.

To our knowledge, the present study is the first intervention trial that implemented FBR developed using LP for nutrition education in adolescent girls and reported comprehensive outcomes on dietary practices, nutrient intakes, hemoglobin levels, and memory performance. Our findings showed that school-based nutrition education can improve intakes of typical problem nutrient of iron and prevent a decrease in nutrient intakes which was otherwise observed in the control group who did not receive nutrition education. With nutrition education which promoted available and affordable food in the local-specific FBR, we observed a positive effect on concentration which was similar to the effect of school-based intervention which provided food supplementation [46].

It is important to consider some limitations when interpreting the study's findings. First, the observed results and the impact of the intervention may have been influenced by the differences between the intervention and control groups with regard to the representativeness of public and private schools and the educational attainment of the mothers. Second, the time interval between the last day of the menstrual cycle and the blood data collection was not taken into account. Third, the results of the memory performance tests may have been impacted by the fact that we did not assess breakfast on the day of cognitive data collection. Fourth, in order to better notice the effect, we used hemoglobin measurements, which are a less sensitive and specific indicator of iron status. It is advised to evaluate iron markers including serum ferritin, transferrin receptor, and body iron storage.

Conclusions

In conclusion, our findings demonstrated that nutrition education with optimized FBR improved dietary practices (promoted nutrient-dense food groups, subgroups, and food items), nutrient intakes (protein, fat, iron) and memory performance. Nutrition education with optimized FBR should be integrated into the school system together with weekly iron supplementation for anemia prevention among these adolescent girls. Future developments of this Remaja ASIK nutrition education to improve nutrition awareness and practices (demand side) should explore more comprehensive components, including more favorable school environments through healthy school canteen (supply side), established school policies, and proper information systems for a measurable effect at the program level.

Abbreviations

BAZ	BMI for Age Z-score
BMI	Body Mass Index
DOHad	Developmental Origins of Health and Disease
FAO	Food and Agriculture Organization
FBDG	Food Based Dietary Guidelines
FBR	Food Based Recommendations
FFQ	Food Frequency Questionnaire
GIR	Glucagon to Insulin Ratio
Hb	Hemoglobin
IEC	Information, Education, and Communication
IST	Intelligenz-Struktur-Test
LNAA	Large Neutral Amino Acids
LP	Linear Programming
NCD	Non Communicable Diseases
WHO	World Health Organization
WISC-3	Wechsler Intelligence Scale for Children third edition

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Authors' contributions
UF, DS, and FW conceived the study. UF, DS, AM, SI, and RK trained the teachers and supervised nutrition education. UF, DS, and RK designed, implemented, and interpreted the study. DS and UF drafted the manuscript. All authors critically reviewed and approved the final manuscript.

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Data availability
The datasets generated and/or analysed during the current study are not publicly available due to further analysis but they are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The study was registered on ClinicalTrials.gov (ID No: NCT03946475) and received ethical clearance approval from the Health Research Ethics Committee, Faculty of Medicine, *Universitas Indonesia*-Cipto Mangunkusumo Hospital (Reference No: 01/UN2.F1/ETIK/2016). Permission from the local government was obtained to conduct the research. Each respondent was provided with complete information about the study. Written informed consent was obtained from all respondents who agreed to participate in the intervention study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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