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Effect of a dietary iron education programme on iron status and intelligence quotient score among schoolchildren in Phatthalung province, southern Thailand

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ABSTRACT

Introduction: The aim of the study was to determine the effect of a dietary iron education programme (DIEP) on children's iron status and intelligence quotient (IQ) score. **Methods:** This pre-test post-test quasi-experimental study with follow-up utilised the Health Belief Model (HBM). Participants were children who had iron deficiency (ID) (serum ferritin <30 µg/L), with anaemia (haemoglobin 80.0 – 114.0 g/L) or without, and their caregivers. The DIEP incorporated group talks, presentations, game-based learning, and cooking. Knowledge of ID and dietary iron, caregivers' perceptions of preventing anaemia and ID in their children, and children's dietary intake, iron status, and IQ score (based on 60-question items adjusted for age) were determined. Statistical tests (one-way MANOVA, Friedman's two-way ANOVA by ranks, Wilcoxon signed-rank test, Monte Carlo exact test) determined differences between pre-test, post-test, and follow-up. **Results:** A total of 32 child-caregiver dyads completed the study; 6.3% (n=2) of children met the Thai dietary reference intake for iron at pre-test versus 28.1% (n=9) at post-test (p=0.039) and 31.3% (n=10) at follow-up (p=0.021). Almost half of the children (n=15) who had ID at pre-test were iron replete at post-test and half (n=16) were iron replete at follow-up (p<0.001). Median IQ scores improved from pre-test to post-test (109.0 vs. 116.0; p=0.010) and were similar at post-test and follow-up (116.0 vs. 117.0; p=0.952). **Conclusion:** Iron status and IQ score improved following the implementation of DIEP. We recommend that this programme serves as a model for similar interventions in other schools.

Keywords: cognitive function; dietary iron education; iron deficiency; iron status

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INTRODUCTION

Nationally representative data from the second South East Asian Nutrition Survey (SEANUTS) indicates that iron deficiency (ID) affects 23.1% of Thai children aged 7.0-12.9 years (Pongcharoen *et al.*, 2024). Anaemia prevalence among children is reported to be highest (approximately 31.2%) in the southern region of Thailand (Suchaorn *et al.*, 2022) and 50.0% of anaemia cases are attributable to ID (WHO, 2015). These data indicate that ID is an important nutritional problem, especially among Thai children in southern Thailand. Moreover, primary school-aged children in the southern region have an intelligence quotient (IQ) score of 98.7, in contrast with the national average of 102.8 for this age group (Department of Mental Health, 2021). Elsewhere, improving the iron status of 6 to 12-year-old children with anaemia has been shown to increase IQ and cognitive scores (Low *et al.*, 2013).

A previous study conducted in Thailand showed that iron supplementation for 16 weeks improved the iron status of schoolchildren (Sungthong *et al.*, 2004). However, supplementation is a short-term curative measure, which is associated with poorer compliance after several weeks due to the occurrence of adverse effects (Silitonga *et al.*, 2023). Promoting dietary diversity and quality is a longer-term strategy for improving iron status. Dietary behavioural change to increase iron intake and iron bioavailability can promote the consumption of a generally more nutrient-dense diet. Therefore, an intervention that focuses on dietary behavioural change is a more holistic approach to improving iron status.

Only a few school-based dietary iron education interventions to improve iron status have been performed in children (Haldar *et al.*, 2012; Garcia-Casal *et al.*, 2011; Khani Jeihooni *et al.*, 2021). Only two studies (Haldar *et al.*, 2012; Garcia-Casal *et al.*, 2011) involved both caregivers and school teachers. Biochemical markers of iron status (serum ferritin, haematocrit, and haemoglobin) improved in two of the studies (Garcia-Casal *et al.*, 2011; Khani Jeihooni *et al.*, 2021). These previous studies had limitations. Haldar *et al.* (2012) did not state whether a biomarker was used to determine the presence of anaemia and they did not include indicators of cognitive performance or follow-up measurements to determine the sustainability of any improvements after a dietary iron education programme (DIEP). Just one study (Khani Jeihooni *et al.*, 2021) applied a theoretical framework of behavioural change.

The traditional dishes of southern Thailand include ingredients that are high in well-absorbed haem iron, such as offal, catfish, mackerel, and beef. The region is well known for its fermented anchovy sauce and spicy sour soups. Some commonly consumed vegetables and spices are high in both non-haem iron and polyphenols, which inhibit its absorption. As such, nutrition education can be tailored to enhance the amount of iron absorbed from each meal. The current study aimed to determine whether a dietary iron education programme (DIEP) involving school teachers, caregivers, and schoolchildren, which utilises the Health Belief Model (HBM) as its theoretical framework, could increase children's iron status and IQ score in a way that could be sustained after the intervention period has ceased.

MATERIALS AND METHODS

Study design

A quasi-experimental (pre-test post-test) design with follow-up was used to test the effect of a DIEP on iron status and IQ score among schoolchildren aged

9-11 years who had ID with or without anaemia. The study duration was 18 weeks. The measurements were carried out at three time points: pre-test (week 1), post-test (week 16), and follow-up (week 18) (Figure 1).

Study setting

The first author purposefully selected one government-administered primary school in the Phatthalung province, southern Thailand. The school was chosen on the basis that it was not

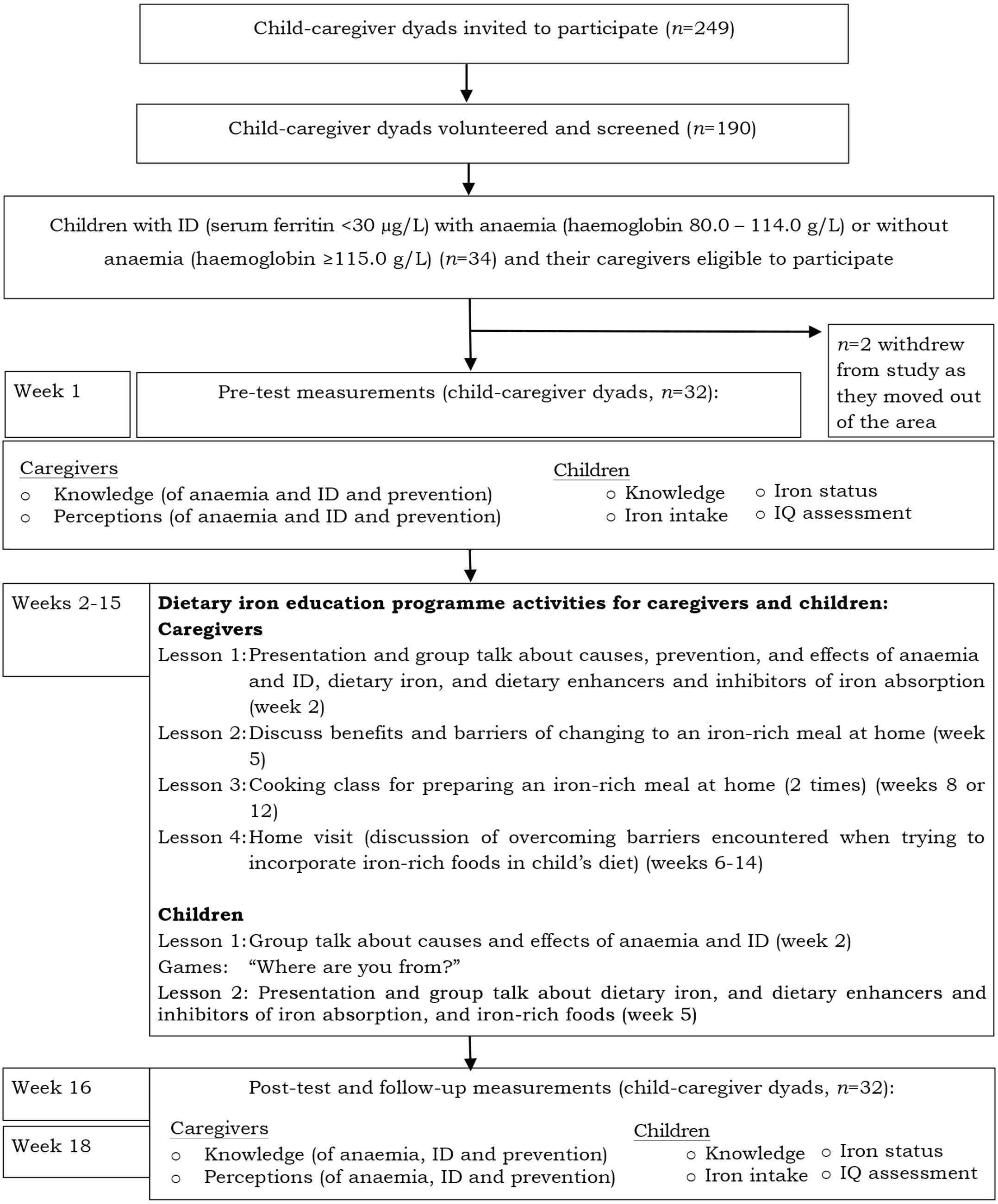

Figure 1. Research flow diagram on recruitment, data collection, and activities for DIEP

included in a government initiative to provide iron supplements to schoolchildren and had at least 200 children studying in grades 4 and 5 (ages 9-11 years).

Sample size

Sample size was calculated using Frison and Pocock's formula (Frison & Pocock, 1992), based on serum ferritin concentration among school-aged children who participated in an intervention study by Rahman *et al.* (2015). The sample size obtained for this study was 34 child-caregiver dyads.

Participants

All children who were studying in grades 4 and 5 of the selected school (*n*=249) and their caregivers were invited to take part in the study. A total of 190 child-caregiver dyads volunteered to participate and were screened. Based on their answers to a set of questions and the children's iron status (determined from a venous blood sample), the following children were excluded from participating in the study: children who were severely anaemic (haemoglobin <80.0 g/L; WHO, 2017), children who had severe illness, female children who were post-menarche, and children who had taken vitamin or mineral supplements within the past month. Children were not screened for hookworm because they had been screened and treated for hookworm infection six weeks prior to the start of this study as part of a local government programme.

The researchers enrolled 34 eligible child-caregiver dyads into the study. All children had ID (serum ferritin <30 μg/L, a recognised threshold for mild ID; Camaschella, 2015, Camaschella, 2019) with anaemia (haemoglobin 80.0 – 114.0 g/L; WHO, 2017) or without anaemia (haemoglobin ≥115.0g/L; WHO, 2017). Informed written consent was obtained from caregivers and children prior to the study. At the start of the study, child-caregiver dyads were instructed that children should not begin taking supplements during the study.

Dietary iron education programme (DIEP)

The programme intervention incorporated activities that focused on the causes, prevention and effects of anaemia and ID, iron-rich foods, and dietary enhancers and inhibitors of non-haem iron absorption (Figure 1).

Before DIEP was implemented in children and their caregivers, the first author delivered two lessons to all eight Grades 4-5 homeroom teachers. These lessons were designed to increase teachers' understanding of anaemia and ID and their prevention, in order to facilitate their assistance in the delivery of DIEP to the children. Teachers also assisted the first author in planning the DIEP and in the delivery of two of the children's lessons in which they discussed, observed, and participated in teaching children about anaemia, ID, and its prevention.

The pre-test and follow-up visits were 18 weeks apart. Separate DIEP activity sessions were conducted for children and caregivers from weeks 2 to 15 in between pre-test and post-test measurements.

Caregivers took part in four 40-minute lessons as part of the DIEP. In lesson 1 (week 2), the first author presented the prevalence and causes of anaemia and ID, focusing on the situation in Phatthalung province, southern Thailand. In lesson 2 (week 5), caregivers listed benefits and barriers related to preparing more iron-rich foods in the home and were invited to brainstorm and share ways to overcome the barriers. Lesson 3 (week 8 or 12) composed of cooking classes for preparing iron-rich meals at home. The final meal, which caregivers voted to prepare, was Thai spicy pork liver salad.

For lesson 4 (weeks 6-14), the first author conducted home visits to discuss and encourage caregivers in their efforts to incorporate more iron-rich meals into their child's diet.

Children received a total of three 60-minute lessons. In lesson 1 (week 2), group talks and games were used to engage the children about the causes and effects of anaemia and ID. The games involved first selecting picture cards with a cause of anaemia and ID from a box, then adding them to a worksheet. The score was the sum of correct answers. Lesson 2 (week 5) focused on iron-rich foods. The children played games that entailed writing names of food ingredients that contained iron, circling pictures of iron-rich foods, and describing their sensations when consuming these foods. An example of one of the games was "choose the winner", which involved children selecting foods that contained the most iron. Both positive and negative answers were brainstormed and discussed. Children were assigned to visit a market with their family to practise recognising iron-rich foods. In Lesson 3 (weeks 8 or 12), children were divided into two sub-groups. The children participated in making two dishes: dry pork wonton with pork liver and steamed mussels, and sour green mini mango salad. The first author and a teacher encouraged children while they were tasting the foods.

Instruments and measurements at pre-test, post-test, and follow-up

Caregivers: Questionnaire

A self-administered questionnaire was developed by the researchers and included socio-demographic characteristics (7 items; pre-test only). It enquired about the caregivers' sex, age, marital status, education level, occupation, number of household members, and family income. The knowledge section assessed caregivers' understanding of the role of body iron, iron deficiency (ID) and anaemia, local iron sources, and enhancers and inhibitors of non-haem iron absorption. There were 15 questions with 'yes', 'no', and 'don't know' answer options. Correct answers were awarded 1, while incorrect answers and 'don't know' were awarded 0. The subsequent section addressed the first four constructs of the HBM: perceived susceptibility, severity, benefits, and barriers to increasing iron-rich food preparation at home to improve iron status. It included 12 items assessed using a Likert scale with options: strongly agree, agree, disagree, neither agree nor disagree, and strongly disagree. Six items were positive questions and six items were negative questions with scores of 1, 2, 3, 4, and 5.

Three experts in nutrition and health education assessed the content validity index (CVI) of the questionnaire, which was 0.97. Cronbach's alpha coefficient test scores were 0.72 (knowledge section) and 0.74 (perceptions section).

Children: Questionnaire

A questionnaire was developed by the researchers and administered to children to measure: 1) personal characteristics, and 2) knowledge (8 questions) of ID and anaemia, local iron sources, and enhancers and inhibitors of iron absorption (CVI 0.98, and Cronbach's alpha coefficient 0.73). Responses were scored: 1 point for correct answers and 0 point for incorrect or 'don't know' answers.

24-hour dietary recall interview

The details of dietary intake for two school days and one weekend day (midnight to midnight) were obtained using the 24-hour dietary recall method.

The researchers conducted 24-hour dietary recall interviews in four phases: quick list, review, food and beverage details, and final review. For the quick list, children were asked to recall the foods and drinks they had consumed on the previous day. The researchers then reviewed everything the children reported and asked them if there was anything omitted from the quick list. After that, the children were asked to estimate the portion sizes of each item using household measures. For the final review, children were asked if they could recall any other items consumed.

Household measures were converted into grams. Data from each child's three 24-hour dietary recalls were then screened, checked, and entered in to INMUCAL-Nutrients V.4.0 (Institute of Nutrition Mahidol University, 2018) to calculate average daily intakes of energy, total iron, haem iron, non-haem iron, vitamin C and animal protein (enhancers of non-haem iron absorption), and fibre and calcium (inhibitors of non-haem iron absorption).

Blood analyses

Iron status was determined from non-fasting venous blood samples. 2 ml of blood was placed into an ethylenediaminetetraacetic acid (EDTA) tube for analysis of haemoglobin concentration, and 3 ml of blood was placed into a lithium heparin tube for serum ferritin and serum C-reactive protein (CRP) analyses. All blood was stored temporarily in a foam box with ice gel packs within three hours. Concentrations of haemoglobin, serum ferritin, and serum CRP were measured by laboratory staffs at the N-Health Laboratory, Bangkok Dusit Medical Service Hospital (BDMS), Songkla province, Thailand, using the haemoglobin assay kit (colorimetric), chemiluminescent immunoassay (CMIA), and high-sensitivity CRP methods, respectively.

Where applicable, serum ferritin concentration was adjusted for acute inflammation (CRP >5 mg/l) by multiplying it with 0.67 (Thurnham *et al.* 2010). Children were then categorised as: 1) iron replete (serum ferritin ≥30 μg/L and haemoglobin ≥115 g /L); 2) ID [serum ferritin <30 μg/L, an accepted threshold for mild ID (Camaschella, 2015; Camaschella, 2019) and haemoglobin ≥115 g /L]; 3) ID with anaemia [serum ferritin <30 μg/L and haemoglobin 80-114 g/L (WHO, 2017)]; and 4) anaemia (haemoglobin 80-114 g/L and serum ferritin level ≥30 μg/L).

Standard progressive matrices (SPM) test

A trained child psychologist assessed each child's general cognitive ability using the parallel version of the 60-item SPM test (Raven, Raven & Court, 2000). The psychologist who administered the test awarded one point for a correct answer and zero for an incorrect answer. Raw scores were converted into IQ scores by drawing comparisons with percentiles and adjusting for age.

Statistical analysis

Statistical analysis was carried out by PASW Statistics for Windows, Version 18.0. (SPSS Inc., Chicago, USA). The Kolmogorov-Smirnov test was used to test the normality of data distribution. Descriptive statistics were calculated for socio-demographic characteristics, knowledge, perceptions, iron intake, iron status, and IQ score. The one-way repeated measures analysis of variance (ANOVA) with post-hoc test was used to analyse between-time point differences in knowledge score among caregivers and haemoglobin concentration in children. Friedman's two-way analysis of variance by ranks and the Wilcoxon signed-rank test were used to compare differences in children's knowledge score, perception score of ID prevention among caregivers, and children's intakes of energy, iron, dietary enhancers and inhibitors of non-haem iron absorption, IQ score, and serum ferritin concentration at pre-test, post-test, and follow-up. The Monte Carlo exact test was used to compare the number of children in grades 4-5 who met the Thai dietary reference intake (DRI) for iron at the three time points. The number of children who were iron replete, iron deficient, iron deficient anaemic, and anaemic were compared at pre-test, post-test, and follow-up using the Friedman's two-way analysis of variance by ranks test. Differences were significantly different when *p*<0.05.

Table 1. Socio-demographic characteristics of child-caregiver dyads (*n*=32)

Characteristics	*n*	*%*
Children		
Age (years), mean±*SD*	10.22 (0.75)	
Sex		
Male	15	46.9
Female	17	53.1
School year (grade)		
4	13	40.6
5	19	59.4
Caregivers		
Age (years)		
20-40	18	56.3
41-60	11	34.4
> 60	3	9.4
Sex		
Male	5	15.6
Female	27	84.4
Marital status		
Single	1	3.1
Married and cohabiting with partner	28	87.5
Married but living separately	1	3.1
Widowed	1	3.1
Divorced	1	3.1
Highest level of education		
Primary school	4	12.5
Junior high school	5	15.6
Senior high school	3	9.4
Vocational School	5	15.6
University	15	46.9
Family income (Baht/month)[†]		
<9,000	7	21.9
9,001-11,000	4	12.5
11,001-18,000	4	12.5
18,001-20,000	7	21.9
≥ 20,001	10	31.3

[†]National Statistical Office of Thailand (2019) 1 US dollar = 33.71 THB (as of 31 October 2024)

Ethical approval and registration

This research was conducted after receiving ethical approval from the Committee for the Ethical Review of

Human Research, Faculty of Public Health, Mahidol University, Thailand (COA: MUPH 2018-048) and registered at clinicaltrials.gov (NCT NCT05878379). This research was conducted in accordance with ethical standards and the Helsinki Declaration of 1975, as revised in 2000.

RESULTS

Sociodemographic data

Thirty-two out of 34 eligible child-caregiver dyads completed the study. Two dyads withdrew from the study as they moved away from the area (Table 1). Children were 10.22±0.75 years old [mean±standard deviation (*SD*)] and 53.1% were females. Over half of the caregivers were aged between 20-40 years old, the majority (84.4%) were females, and most (87.5%) were married and/or cohabiting with their partner. Almost half of the caregivers had completed a university education and approaching one third had a monthly family income of more than 20,000 Baht (593 USD, as of 31 October 2024). All of the caregivers were parents of the participating children, except for six grandparents.

Knowledge and perceptions in caregivers

Knowledge of anaemia and ID, dietary iron, and dietary enhancers and inhibitors of iron absorption among caregivers increased from pre-test to post-test (*p*=0.028), but decreased from post-test to follow-up (*p*=0.004) (Table 2). The follow-up knowledge score was similar to the pre-test score (*p*=0.089).

The caregivers' perceptions of children's susceptibility to anaemia and ID increased from pre-test to post-test (*p*<0.001) and from post-test to follow-up (*p*=0.024). Perceived severity of ID in relation to cognitive function increased from pre-test to post-test (*p*=0.002) and was similar from post-test to follow-up (*p*=0.662), but remained greater at follow-up than at pre-test (*p*=0.007). There was also a pre-test to post-test increase in perceived benefits of changing behaviour related to preparing more iron-rich meals (*p*=0.001), although it was followed by a decrease from post-test to follow-up (*p*=0.001), which at follow-up was similar to the pre-test level (*p*>0.901). Pre-test and post-test perceptions of barriers for changing behaviour related to preparing more iron-rich meals in the home did not change (*p*=0.532) and decreased from post-test to follow-up (*p*=0.002); the score at follow-up was lower than the score at pre-test (*p*=0.012).

Knowledge and dietary intake in children

Although children's knowledge score improved from pre-test to post-test (*p*<0.001), this improvement was not

Table 2. Outcome variables among caregivers at pre-test, post-test, and follow-up (*n*=32)

	Pre-test	*Post-test (16th week)*	*Follow-up (18th week)*
Knowledge score, mean±*SD*	7.5±2.5^{a}	9.3±2.5^{b}	8.9±2.4^{a}
HBM score, median (25th, 75th percentile)			
Perceived susceptibility	10.0 (9.0-11.0)^{a}	11.0 (10.5-12.5)^{b}	11.0 (10.0-12.0)^{c}
Perceived severity	9.0 (8.0-10.0)^{a}	10.5 (9.0-11.5)^{b}	10.0 (9.0-11.0)^{c}
Perceived benefits	12.0 (10.5-13.0)^{a}	14.0 (12.0-15.0)^{b}	12.0 (11.0-13.0)^{a}
Perceived barriers	7.0 (6.0-10.0)^{a}	8.0 (6.0-9.0)^{a}	6.0 (5.0-7.0)^{b}

SD: Standard deviation; HBM: Health Belief Model

Different superscript letters indicate significant differences (*p*<0.05) in scores determined using one-way repeated measures analysis of variance.

sustained as the knowledge score decreased from post-test to follow-up (*p*=0.008; Table 3).

Median intakes of total dietary iron (haem + non-haem) increased from pre-test to post-test (*p*=0.021) and remained similar at follow-up to the post-test value (Table 3). When analysed separately, haem iron intake did not change from pre-test to post-test (*p*=0.782), whereas there was a decrease from post-test to follow up (*p*=0.002). In contrast, non-haem iron intake increased from pre-test to post-test (*p*=0.012) and was similar to post-test intake at follow-up (*p*=0.901). At follow-up, the consumption of non-haem iron was greater than at pre-test (*p*=0.018). Only two children (6.3%) met the Thai DRI for iron at pre-test, but this rose to nine (28.1%) at post-test (*p*=0.039) and 10 (31.3%) at follow-up (*p*=0.021).

Pre-test to post-test changes in intakes of animal protein and vitamin C (both enhancers of non-haem iron absorption) were not statistically significant (Table 3). Average intake of vitamin C increased from post-test to follow-up (*p*=0.003) and remained higher at follow-up than at pre-test (*p*=0.001). Consumption of animal protein decreased from post-test to follow-up (*p*=0.001) and was lower at follow-up than at pre-test (*p*=0.037). Fibre intakes were similar at pre-test and post-test. Calcium consumption also remained similar throughout the study.

Iron status in children

Some children had raised CRP (> 5 mg/l) at pre-test (*n*=1), post-test (*n*=2), and follow-up (*n*=1), which resulted in an inflammation-related rise in serum ferritin concentration. After adjusting for this (Thurnham *et al.* 2010), 15 children (46.9%) who

Table 3. Knowledge score, dietary intakes, and IQ score in children at pre-test, post-test, and follow-up (*n*=32)

	Pre-test	*Post-test (16th week)*	*Follow-up (18th week)*
Knowledge score, median (25th, 75th percentile)	4 (3.0, 5.0)^{a}	6 (6.0, 6.8)^{b}	5 (4.0, 6.0)^{a}
Dietary intake, median (25th, 75th percentile)			
Energy (kcal/d)	1329 (1105, 1683)^{a}	1355 (1144, 1764)^{a}	1070 (869, 1435)^{a}
Iron			
Total iron (mg/d)	7.6 (6.1, 9.6)^{a}	8.51 (6.8, 12.4)^{b}	6.9 (5.7, 14.3)^{a,b}
Haem iron (mg/d)	4.1 (3.0, 5.1)$^{a, b}$	4.2 (2.9, 6.9)^{a}	2.6 (1.6, 4.1)^{b}
Non-haem iron (mg/d)	2.7 (1.8, 3.9)^{a}	4.0 (2.2, 5.8)^{b}	3.6 (2.7, 6.4)^{b}
Enhancers of non-haem iron absorption			
Animal protein (g/d)	36.3 (27.3, 52.7)^{a}	54.3 (33.9, 70.6)^{a}	24.3 (17.3, 42.1)^{b}
Vitamin C (mg/d)	12.1 (5.7, 25.5)^{a}	14.7 (5.3, 28.5)^{a}	28.0 (17.6, 73.4)^{b}
Inhibitors of non-haem iron absorption			
Fibre (g/d)	4.1 (2.7, 6.1)^{a}	6.4 (3.7, 7.9)^{a}	7.7 (3.9, 13.0)^{a}
Calcium (mg/d)	316.5 (276.0, 441.2)^{a}	329.3 (224.1, 441.6)^{a}	275.5 (161.4, 414.8)^{a}
IQ score median (25th, 75th percentile)	109.0 (100.8,121.0)^{a}	116.0 (110.0,135.0)^{b}	117.5 (105.0,133.0)^{b}

IQ: Intelligence quotient

Different superscript letters indicate significant differences (*p*<0.05) in score between time points.

had mild iron depletion with or without anaemia at pre-test were iron replete at post-test and 16 (50%) were iron replete at follow-up ($p<0.001$) (Table 4). The mean±SD concentration of haemoglobin increased from 123.2±9.9 g/L at pre-test to 126.5±9.7 g/L and 127.3±9.5 g/L at post-test and follow-up ($p<0.001$), respectively. Following the intervention, median (25th, 75th percentile) serum ferritin concentration also increased by 6-7 μg/L; from 24.5 (19.3, 28.4) μg/L at pre-test to 31.1 (22.9, 40.0) μg/L and 30.1 (20.8, 40,5) μg/L at post-test and follow-up ($p=0.001$), respectively. Overall, the iron status of children improved from pre-test to post-test and was similar at post-test and follow-up.

IQ scores in children

Median (25th, 75th percentile) IQ scores improved from pre-test to post-test [109.0 (100.8, 121.0) vs. 116.0 (110.0,135.0); $p=0.010$] and were similar at post-test and follow-up [116.0 (110.0, 135.0) vs. 117.5 (105.0, 133.0); $p=0.952$] (Table 3).

DISCUSSION

We designed and implemented a DIEP to determine whether it could improve iron status and subsequently improve IQ scores among children. The study was purposively conducted in the southern region of Thailand, which has the highest prevalence rate of anaemia among children (Suchaorn *et al.*, 2022). Intake of total dietary iron and specifically non-haem iron increased. Almost half of the children who had ID with or without anaemia at pre-test were iron replete at post-test and half were iron replete at follow-up. Median IQ scores improved from pre-test to post-test and were similar at post-test and follow-up.

The increased consumption of dietary iron from pre-test to post-test was attributable to an increase in non-haem iron intake, which indicated that the

Table 4. Children's iron status at pre-test, post-test, and follow-up ($n=32$)

	Pre-test	*Post-test (16th week)*	*Follow-up (18th week)*	*p-value*
Haemoglobin (g/L), mean±SD	123.2±9.9	126.5±9.7	127.3±9.5	<0.001
Serum ferritin (μg/L), median (25th, 75th percentile)	24.47 (19.26, 28.38)	31.05 (22.85, 40.02)	30.06 (20.78, 40.48)	0.001
Iron status, *n* (%)				
Iron replete[†]	0 (0)	15 (46.9)	16 (50.0)	<0.001
ID[‡]	24 (75.0)	13 (40.6)	15 (46.9)	
IDA[§]	8 (25.0)	4 (12.5)	0 (0)	
Anaemia[¶]	0 (0)	0 (0)	1 (3.1)	

ID: Iron deficiency; IDA: Iron deficiency anaemia

[†] serum ferritin ≥30 μg/L and haemoglobin ≥115 g/L; [‡] serum ferritin <30 μg/L and haemoglobin ≥115 g/L; [§] serum ferritin <30 μg/L and haemoglobin 80-114 g/L; [¶] serum ferritin level ≥ 30 μg/L and haemoglobin 80-114 g

consumption of plant-based sources of iron such as vegetables had increased. Although some children consumed more animal protein from pre-test to post-test, the absence of a simultaneous increase in haem iron intake might suggest that the animal proteins consumed were not iron-rich sources. In terms of our participants' financial access to foods of animal origin, approaching one third of the children's caregivers had a monthly family income of more than 20,000 Baht (593 USD, as of 31 October 2024), compared with an average of 26,621 Baht per month for this region at the time that our study was conducted (National Statistical Office of Thailand, 2022). Increasing the consumption of foods of animal origin, particularly more expensive choices, such as beef, may have been a less affordable option for some families or may simply not have suited the taste preferences of 10 to 11-year-old participants in our study.

Previous studies have also demonstrated improvements in dietary habits related to iron nutrition among children and adolescents immediately after nutrition education for 4-16 weeks (Amani & Soflaei, 2006; Alaofè *et al.*, 2009; Khani Jeihooni *et al.*, 2021). Game-centred activities can be effective educational tools to learn healthy eating habits (Viggiano *et al.*, 2015; Joyner *et al.*, 2017). Furthermore, cooking classes encouraged the children in this study to accept iron-rich meals and made it easier for them to recall types of iron-rich foods. At post-test, 100% and 81.3% answered correctly for items 5 and 6 (tested knowledge of iron-rich foods) compared with 71.9% and 46.9% at pre-test.

Dietary change initiatives aim to be long-term approaches to improving health indicators (Bel-Serrat *et al.*, 2022). However, as with all lifestyle changes, it can be challenging to sustain dietary changes even for a short time following the end of an intervention. Practical activities, such as cooking lessons, that we utilised in our study–have been shown to improve the sustainability of dietary behavioural changes (DeCosta *et al.*, 2017). Nevertheless, dietary changes may not be sustained in the long term due to cost, availability, accessibility, and absence of social support.

The DIEP emphasised iron-rich meals and foods with enhancers of iron absorption. Improving dietary iron bioavailability by including more dietary enhancers of non-haem iron absorption can lead to a rise in iron absorption (Conway *et al.*, 2006). Vitamin C and animal protein intakes increased in some participants from pre-test to post-test and consumption of the former significantly rose from post-test to follow-up. This is expected to improve non-haem iron bioavailability (Hurrell & Egli, 2010) and could be associated with improved iron status in our study participants, of whom 50% (n=16) were iron replete at the time of follow-up. This may explain why the overall iron status of the children improved after DIEP, despite no increase in haem iron intake.

Our study also determined whether any improvement in IQ score could be sustained after the intervention. Although the determinants of IQ are multifactorial, increases in IQ and global cognitive scores have been seen after improving the iron status of anaemic 6 to 12-year-old children (Low *et al.*, 2013). IQ score increased from pre-test to post-test and remained similar at follow-up. Hence, in our study, we observed both an improvement in biomarkers of iron status (haemoglobin and serum ferritin concentrations) and IQ score among the children. Average IQ scores in the current study increased by 7 points and the observed change was similar to the 6-point average IQ score rise which Sungthong *et al.* (2004) reported after once-weekly iron supplementation in schoolchildren for 16 weeks.

Our research has several limitations. A one-group pre-test post-test quasi-experimental design with follow-up was applied due to time and budget constraints. The possibility of the effect of confounding factors with regards to the improvement in iron status and IQ score cannot be ruled out. Additionally, IQ scores showed improvement due to practice effects. The improvement could have reflected learning, as the test was conducted three times within a short span of time (18 weeks). Nevertheless, other factors that could affect iron status and IQ score over the period of the intervention, such as changes in school meals or school activities, were not present. DIEP was implemented at the school during lesson time and some children left the classroom before some lessons had finished. We collected dietary data directly from the children (mostly aged 10-11 years) using the 24-hour dietary recall method. However, a systematic review of dietary assessment techniques concluded that children may not accurately self-report their own dietary intake until around the age of 12 years (Burrows, Martin & Collins, 2010). Therefore, the dietary records may not have provided an accurate account of the children's dietary intake, despite researchers receiving training and helping children to estimate portion sizes using household measures. Lastly, room changes during the study may have affected children's performance during the assessment of IQ score.

The strengths of this study should be acknowledged. The 24-hour dietary recall was conducted over two school days and one weekend day, which has been suggested as a way of improving the representativeness of dietary data collected from children (Burrows *et al.*, 2010). All IQ tests were conducted by the same trained child psychologist using the 60-item SPM parallel version test. Another strength of this study was the determination of iron status using standardised biochemical indicators together with adjustment of serum ferritin concentration for acute inflammation (as indicated by raised serum CRP) using an established method (Thurnham *et al.*, 2010). With regards to DIEP, it included practical activities that promote active learning; the programme was carefully designed with local dietary preferences in mind and utilised a theoretical framework. Lastly, this study involved school teachers, caregivers, and schoolchildren, and it was conducted in a region of Thailand that had the highest anaemia prevalence and therefore a need for intervention.

CONCLUSION

There were measurable improvements in knowledge and perceptions related to iron status and dietary behavioural change, as well as in children's dietary intake following this intervention, which was designed around key constructs of the HBM. In conclusion, iron status and IQ score increased at post-test and the increases were sustained two weeks later at follow-up. Our findings have implications for future approaches to improving iron status via the modification of dietary behaviours in schoolchildren. A DIEP that is based on a strong theoretical framework and created with local dietary preferences in mind can yield positive results; thus, we recommend that this programme serves as a model for similar interventions in other schools.

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Authors' contributions

Simla W, principal investigator, conducted the study, carried out data analysis and interpretation, co-wrote the manuscript, and co-revised the manuscript; Hutchinson C, major advisor, advised on study methodology, data collection and interpretation, co-wrote the manuscript, and co-revised the manuscript; Tansukul S, co-advisor, advised on study methodology and data interpretation; Tipayamongkholgul M, co-advisor, advised on study methodology, data analysis and interpretation; Pruksa S, co-advisor, advised on study methodology, data collection and interpretation. All authors read and approved the final version of the manuscript.

Conflicts of interest

All authors have no conflict of interest to declare.

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