



● ORIGINAL ARTICLE

Hematological and Micronutrient Profile among Sudanese Schoolchildren in Egypt and Sudan

Albara Ahmed^{1,2,✉}, Mustafa B. M. Ahmed¹, Osman A. O. Ahmed¹, Hadia N. M. S. Ahmed¹, Fairoz A. M. S. Abdelrahman¹, Fatima Y. A. Alshaikh¹, Saif Eldowla Ayoub³, Mohamed E. Abdelwadoud⁴

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Abstract

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BACKGROUND

Iron and vitamin B12 deficiencies are among the common health problems of school-age children worldwide, affecting physical growth and academic performance. The Sudanese conflict has displaced large numbers of families to neighboring countries, with substantial changes in living conditions and diet. This study compared the hematological and micronutrient profiles of Sudanese schoolchildren in Egypt and Sudan.

METHODS

A cross-sectional analytical study was conducted between May and July 2025 in one school in Giza, Egypt, and one in Karrari, Khartoum. Of 224 targeted students, 120 were assessed (70 Egypt, 50 Sudan; response rate 53.6%). Complete blood count was performed on a Sysmex KX-21, thin films were examined microscopically, and serum iron and vitamin B12 were measured on an AutoLumo A1000. Groups were compared by independent-samples t-test and re-analyzed by ANCOVA with age and gender as covariates.

RESULTS

Unadjusted differences were significant for MCH ($p = 0.020$), RDW ($p = 0.003$), platelet count ($p < 0.001$), total WBC ($p = 0.045$), lymphocytes, monocytes, eosinophils and serum iron (all $p < 0.001$). Hemoglobin, MCV, MCHC, neutrophils and vitamin B12 did not differ. After adjustment for age and gender, all retained significance except MCH (adjusted $p = 0.080$) and total WBC (adjusted $p = 0.056$). Blood films showed no significant morphological changes in either group.

CONCLUSION

The two groups differed in several hematological and micronutrient parameters, most differences persisting after adjustment. Overt anemia was not prevalent in either group. The findings support regular hematological screening of displaced Sudanese children.

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CORRESPONDENCE

Albara Ahmed

albaraa1983@yahoo.com

AFFILIATIONS

¹ Department of Hematology, Medical Laboratory Science Program, Al-Fajr College for Science & Technology, Khartoum, Sudan.

² Department of Hematology, Faculty of Medical Laboratory Sciences, El-Razi University, Khartoum, Sudan.

³ Department of Microbiology, Medical Laboratory Science Program, Al-Fajr College for Science & Technology, Khartoum, Sudan.

⁴ Department of Histopathology, Faculty of Medical Laboratory Sciences, Nile University, Khartoum, Sudan.

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KEYWORDS

Anemia • Iron • Vitamin B12 • Schoolchildren • Sudan



Introduction

Micronutrient deficiency in the body is a common nutritional problem worldwide affecting people of different ages, genders, and backgrounds. When the body lacks enough hemoglobin, the biomolecule responsible for carrying oxygen to body tissues, oxygen-carrying capacity is reduced, leading to physical and mental symptoms that affect daily activities¹. Red blood cells (RBCs) play a vital role in normal human body function, basically through their role in transporting oxygen and carbon dioxide². Clinical symptoms vary depending on the severity and underlying cause. Common symptoms include fatigue, weakness, shortness of breath, dizziness, and pale skin. Because these symptoms can be subtle or mistaken for other conditions, anemia is sometimes known as a "silent" disorder³. Types of anemia include: vitamin deficiency, resulting from a deficiency in essential nutrients (e.g., vitamin B12 or folate), anemia of chronic disease, and hereditary forms like sickle cell and thalassemia⁴.

Vitamin B12, or cobalamin, is a water-soluble vitamin that plays a vital role in hematopoiesis and maintaining healthy nerve cells⁵. Vitamin B12 is also necessary for overall energy levels, brain function, and disease prevention⁵. B12 deficiency may lead to megaloblastic anemia, characterized by abnormally large and dysfunctional erythrocytes^{6,7}. B12 absorption requires intrinsic factor produced by stomach parietal cells. Certain medical conditions such as pernicious anemia or gastrointestinal abnormalities can interfere with B12 absorption and lead to deficiency⁸.

Iron is an essential nutrient that plays a vital role in maintaining body health. It is a key component of hemoglobin responsible for oxygen transport. Without enough iron, the body cannot produce enough healthy RBCs, leading to iron deficiency anemia⁹. Iron is also involved in energy production, immune system function, hormone synthesis, and cognitive development¹⁰. There are two types of iron: heme iron (found in animal products) and non-heme iron (found in plant-based sources)¹⁰. Consuming non-heme iron with vitamin C-rich foods enhances its absorption¹⁰. Iron supports numerous physiological functions in the human body⁹.

Globally, anemia in school-aged children remains a serious public health problem, affecting growth,

development, and educational performance¹¹. The military conflict in Sudan has resulted in the displacement of large populations to internal regions and neighboring countries such as Egypt^{12,13}. Children are among the groups most affected by this displacement.¹⁴ This study aimed to assess and compare the hematological and micronutrient profiles of Sudanese schoolchildren residing in Giza, Egypt, and Karrari, Sudan.

Materials and Methods

Study Design and Study Area

The study followed a cross-sectional analytical design conducted among Sudanese schoolchildren in two schools located in Egypt and Sudan, in the period between May and July 2025. The two research localities were selected because they were mostly populated by Sudanese families during the military conflict that erupted in Sudan in April 2023; one school in each country was selected. The school in Giza Governorate, Egypt, had attracted Sudanese families who chose to emigrate to Egypt and had their children enrolled in schools in that locality. Karrari Locality in Khartoum was selected to provide a comparable educational and health-screening baseline for children remaining in Sudan during the study period. The two research localities provided comparable educational and health-screening environments for Sudanese schoolchildren during the period of the study.

The study population was schoolchildren aged 8–16 years, enrolled in the selected schools, who were present during the data-collection period. Children with known chronic illnesses, acquired or inherited hematologic disorders, who received recent blood transfusion, or who had acute infections at the time of sampling were excluded from the study.

Sample Size

The following equation was used to calculate the sample size:

$$n = Z^2 \times PQ / e^2$$

Where n indicates the minimum required sample size, Z is the desired confidence level taken as 1.96 for a 95% confidence level, P represents the expected prevalence of iron deficiency anemia among Sudanese schoolchildren taken as 17.8% based on previous study conducted in

River Nile State, Sudan, by Osman et al. ¹, Q is the complement of $P = 1 - P$, and e is the margin of error taken as 0.05.

$$n = 1.96^2 \times 0.178 \times 0.822 / 0.05^2 = 224.8, \text{ rounded to } 224.$$

The sample was divided equally between Egypt and Sudan.

Quality Control and Pre-analytical Standardization

Both laboratory sites used identical analytical platforms: the Sysmex KX-21 automated hematology analyzer for CBC and the AutoLumo A1000 analyzer for serum iron and vitamin B12 testing. Standard calibration protocols and daily internal quality control (IQC) runs were executed per manufacturer guidelines ^{15,16}. Blood samples were collected during standard morning school hours, transported in cold boxes, and processed on the day of collection following standardized standard operating procedures ¹⁷.

Sampling Technique

A simple random sampling approach was used in both countries. Each school administration provided an updated list of enrolled students within the eligible age range. Using this list as the sampling frame, names of the participants were selected through a lottery process to ensure unbiased representation.

Data Collection Methods and Techniques

Data collection took place during scheduled school hours by trained research personnel, who obtained the data using a structured questionnaire through direct interview. The questionnaire included students' demographic data, including gender and educational level. These data were later incorporated with students' hematologic data.

Sample Collection and Handling

Five milliliters of venous blood were collected from each participant; a tourniquet was applied to the upper arm, and a blood sample was collected under aseptic conditions following standard clinical procedures ¹⁷; 2 mL were placed in EDTA tubes for hematological evaluation (complete blood count); the remaining volume was used to obtain serum for the evaluation of serum iron and vitamin B12. Samples were transported in temperature-controlled containers to accredited laboratories in each country for analysis.

Laboratory Equipment and Analytical Methods

Hematological Analysis

Complete blood count (CBC) was analyzed using the cell counter full automated hematology analyzer (Sysmex KX-21, Sysmex, Japan), an automated device used to measure hemoglobin levels, red cell indices (MCV, MCH, MCHC), and white cell count, among other blood indices that are calculated directly or indirectly.

CBC Principle

The cell counter "Coulter principle" depends on detecting and measuring changes in electric resistance or impedance produced by a cell suspended in a diluent (an electrically conductive liquid) passing through a small aperture.

Blood Morphology

A drop of venous EDTA anticoagulated blood was placed onto a clean glass slide, then spread to create a thin film. After air-drying, the film was fixed and stained using Giemsa stain. The rainbow area in the stained slides was then examined microscopically under oil immersion to evaluate blood cell morphology and identify cellular abnormalities.

Serum Iron Assay

Serum Iron Assay: Venous blood was collected under aseptic conditions; serum was obtained by centrifugation at 3000 rpm for 5 minutes and separated into plain tubes. Serum iron concentration was measured spectrophotometrically using the AutoLumo A1000 automated analyzer (Autobio Diagnostics Co., Ltd., Zhengzhou, China; Cat. No. A29102, Package Insert Version 2.1) ¹⁵. Briefly, 20 μ L of serum was aspirated; iron bound to transferrin was released in a (Fe^{3+}) to ferrous (Fe^{2+}) state and reacted with a chromogenic substrate to form a colored complex. Absorbance was measured automatically over an analytical range of 10.0–1000.0 $\mu\text{g/dL}$ ¹⁵.

Serum Vitamin B12 Assay: Serum vitamin B12 levels were quantitatively determined using a competitive chemiluminescence microparticle immunoassay (CLIA) on the AutoLumo A1000 analyzer (Autobio Diagnostics Co., Ltd., Zhengzhou, China; Cat. No. A29204, Package Insert Version 2.3) ¹⁶. A 50 μ L serum sample was incubated with magnetic microparticles coated with intrinsic factor and enzyme-labeled vitamin B12 conjugate. After competitive binding and automated washing, a chemiluminescent substrate was added, and emitted light was measured by a photomultiplier tube.

The assay had a calibration linearity range (measuring range) of 50.0–2000.0 pg/mL ¹⁶.

Data Analysis

Continuous variables were summarized as mean $\pm$ standard deviation (SD) with 95% confidence intervals (95% CI), and categorical variables as frequencies and percentages. The distribution of continuous variables was assessed before analysis, and between-group comparisons were performed using the independent-samples t-test, with Welch's correction applied where variances were unequal. Effect size was evaluated using Cohen's d ¹⁸. Because the two groups differed at baseline in age and gender, each outcome was re-analyzed by analysis of covariance (ANCOVA) with country of residence as the fixed factor and age and gender as covariates; adjusted mean differences, 95% CIs and p -values are reported. A two-sided p -value below 0.05 was considered statistically significant. All analyses were performed using SPSS version 26.

Ethical Considerations

Primary ethical approval for this cross-sectional study was granted by the Research Ethics Committee at Al-Fajr College for Science and Technology, Khartoum, Sudan. Field data collection and venous blood sampling, were conducted under official administrative permission and institutional authorization from the participating schools' authorities. Participation was entirely voluntary. Written informed consent was obtained from the parents or legal guardians of all participating minors before blood collection, and verbal assent was obtained from participating children. All specimens were handled following standard clinical guidelines, and participant data were anonymized using unique identification codes. All study procedures adhered to the ethical principles outlined in the Declaration of Helsinki ¹⁹.

Results

Participant Characteristics

The study targeted 224 students, who were divided equally between Egypt and Sudan, with 112 students in each. However, due to conflict-related access limitations in Sudan and cost constraints in both sites, only 50 students residing in Sudan (Sudan group) could be

assessed, giving a 44.6% response rate. While 70 students residing in Egypt (Egypt group), with a 62.5% response rate, were successfully assessed. The final achieved sample size was therefore 120 participants, giving a total response rate of 53.6%. The variables collected in the study included students' educational level, which was comparable between the two groups, with the intermediate level slightly higher in the Sudan group than in the Egypt group (68.0% and 64.3%, respectively). Regarding gender, the proportion of male students was higher in the Egypt group than in the Sudan group (57.1% and 40.0%, respectively).

Red Cell Parameters

The mean hemoglobin level, MCV, and MCHC showed no statistically significant differences between the Egypt group and the Sudan group (12.13 ± 1.79 g/dL vs. 12.16 ± 0.99 g/dL, $p = 0.906$; 83.78 ± 9.54 fL vs. 84.38 ± 5.03 fL, $p = 0.656$; and 32.35 ± 1.35 g/dL vs. 32.64 ± 0.99 g/dL, $p = 0.181$, respectively). MCH and RDW showed a significant decrease in the Egypt group compared to the Sudan group in the unadjusted analysis (27.61 ± 3.48 pg vs. 28.68 ± 1.33 pg, $p = 0.020$; and $14.05 \pm 1.86\%$ vs. $14.88 \pm 1.10\%$, $p = 0.003$, respectively) (Table 1). After adjustment for age and gender (ANCOVA), RDW maintained its statistical significance (adjusted $p = 0.005$), whereas MCH lost statistical significance (adjusted $p = 0.080$) (Table 2).

Platelets and White Blood Cells

Platelet count (PLT) was significantly higher in the Egypt group compared to the Sudan group ($289.26 \pm 108.16 \times 10^3/\mu\text{L}$ vs. $214.80 \pm 49.10 \times 10^3/\mu\text{L}$, $p < 0.001$; adjusted $p < 0.001$). Regarding the white blood cell profile, except for neutrophils ($p = 0.151$, adjusted $p = 0.242$), total and differential counts showed significant differences between the two groups. The Egypt group demonstrated significantly higher levels for TWBC ($6.09 \pm 2.05 \times 10^3/\mu\text{L}$ vs. $5.42 \pm 1.54 \times 10^3/\mu\text{L}$, $p = 0.045$; adjusted $p = 0.056$), lymphocytes ($40.17 \pm 10.70\%$ vs. $33.60 \pm 7.76\%$, $p < 0.001$; adjusted $p = 0.001$), and monocytes ($8.89 \pm 5.59\%$ vs. $4.80 \pm 1.39\%$, $p < 0.001$; adjusted $p < 0.001$), while eosinophils were significantly lower in the Egypt group ($1.50 \pm 0.72\%$ vs. $2.94 \pm 1.38\%$, $p < 0.001$; adjusted $p < 0.001$) (Table 1 and Table 2).

Blood Film Morphology

Peripheral blood film examination showed no significant morphological changes in either group.

Table 1. Participant characteristics and hematological and micronutrient profile of the two groups (N = 120).

Parameter	Egypt Group (n = 70) Mean ± SD	Sudan Group (n = 50) Mean ± SD	Mean Difference (95% CI)	t	Cohen's d	p-value
Demographics						
Age (years)	12.21 ± 2.76	10.48 ± 3.41	1.73 (0.59 to 2.88)	2.97	0.57	0.004*
Complete Blood Count						
Hemoglobin (g/dL)	12.13 ± 1.79	12.16 ± 0.99	-0.03 (-0.53 to 0.47)	-0.12	-0.02	0.906
MCV (fL)	83.78 ± 9.54	84.38 ± 5.03	-0.60 (-3.23 to 2.03)	-0.45	-0.08	0.656
MCH (pg)	27.61 ± 3.48	28.68 ± 1.33	-1.08 (-1.97 to -0.18)	-2.36	-0.39	0.020*
MCHC (g/dL)	32.35 ± 1.35	32.64 ± 0.99	-0.29 (-0.71 to 0.13)	-1.35	-0.24	0.181
RDW (%)	14.05 ± 1.86	14.88 ± 1.10	-0.84 (-1.37 to -0.30)	-3.08	-0.53	0.003*
Platelet count (×10 ³ /μL)	289.26 ± 108.16	214.80 ± 49.10	74.46 (45.69 to 103.22)	5.07	0.84	< 0.001*
Total WBC (×10 ³ /μL)	6.09 ± 2.05	5.42 ± 1.54	0.66 (0.02 to 1.31)	2.03	0.36	0.045*
Differential White Cell Count (%)						
Neutrophils	46.34 ± 11.40	44.01 ± 6.06	2.32 (-0.83 to 5.48)	1.44	0.24	0.151
Lymphocytes	40.17 ± 10.70	33.60 ± 7.76	6.57 (3.27 to 9.88)	3.90	0.69	< 0.001*
Monocytes	8.89 ± 5.59	4.80 ± 1.39	4.09 (2.72 to 5.45)	5.86	0.93	< 0.001*
Eosinophils	1.50 ± 0.72	2.94 ± 1.38	-1.44 (-1.86 to -1.02)	-6.77	-1.38	< 0.001*
Micronutrients						
Serum iron (μg/dL)	116.99 ± 70.53	77.94 ± 10.99	39.05 (22.13 to 55.97)	4.52	0.72	< 0.001*
Vitamin B12 (pg/mL)	466.56 ± 273.35	469.80 ± 89.05	-3.24 (-71.87 to 65.39)	-0.09	-0.01	0.927

SD, standard deviation; CI, confidence interval; MCV, mean corpuscular volume; MCH, mean corpuscular hemoglobin; MCHC, mean corpuscular hemoglobin concentration; RDW, red cell distribution width; WBC, white blood cell. Comparisons by independent-samples t-test with Welch's correction where variances were unequal. * p < 0.05.

Micronutrient Profile

Serum iron levels were significantly higher in the Egypt group compared to the Sudan group (116.99 ± 70.53 μg/dL vs. 77.94 ± 10.99 μg/dL, p < 0.001; adjusted p <

0.001). In contrast, serum vitamin B12 levels showed no statistically significant difference between the two groups (466.56 ± 273.35 pg/mL vs. 469.80 ± 89.05 pg/mL, p = 0.927; adjusted p = 0.685) (Table 1 and Table 2).

Table 2. Unadjusted versus age- and gender-adjusted multivariable analysis (ANCOVA).

Outcome Parameter	Unadjusted Mean Difference (Egypt - Sudan)	Adjusted Effect (β) (Egypt vs Sudan)	Adjusted 95% CI	Adjusted p-value
Hemoglobin (g/dL)	-0.03	-0.05	-0.62 to 0.53	0.872
MCV (fL)	-0.60	-0.83	-3.89 to 2.24	0.594
MCH (pg)	-1.08	-0.94	-2.01 to 0.12	0.080
MCHC (g/dL)	-0.29	-0.18	-0.64 to 0.28	0.436
RDW (%)	-0.84	-0.88	-1.48 to -0.28	0.005*
Platelet count (×10 ³ /μL)	+74.46	+70.80	36.98 to 104.61	< 0.001*
Total WBC (×10 ³ /μL)	+0.66	+0.68	-0.02 to 1.38	0.056
Neutrophils (%)	+2.32	+2.12	-1.45 to 5.70	0.242
Lymphocytes (%)	+6.57	+6.18	2.51 to 9.86	0.001*
Monocytes (%)	+4.09	+4.60	3.03 to 6.18	< 0.001*
Eosinophils (%)	-1.44	-1.49	-1.89 to -1.09	< 0.001*
Serum iron (μg/dL)	+39.05	+37.92	17.23 to 58.61	< 0.001*
Vitamin B12 (pg/mL)	-3.24	-17.01	-99.86 to 65.85	0.685

β, adjusted mean difference from analysis of covariance with country of residence as the fixed factor and age and gender as covariates; CI, confidence interval. Positive values indicate higher means in the Egypt group. * p < 0.05.

Discussion

The study was conducted in the duration between May and July 2025 on Sudanese primary and intermediate school children, 70 from Giza Governorate (Egypt group)

and 50 from Karrari Locality (Sudan group) of the same age group, to assess their hematological and micronutrient parameters.

The present study demonstrated a statistically insignificant difference in hemoglobin levels between



the Egypt group and Sudan group (12.13 g/dl and 12.16 g/dl, P-value 0.906). This finding was consistent with Mohammed Saeed Elsamani Eltayeb et al (2016) ²⁰, who reported low mean hemoglobin levels of 11.7g/dl among Sudanese children (mean age 12.3 years), and data also consistent with Tariq E. Elmissbah (2024) ²¹, who concluded a decreased mean hemoglobin of 12.0 among primary school students aged between 6–14 y in Khartoum, Sudan. These findings indicate that overt anemia was not prevalent among the studied population of displaced Sudanese children in Giza during the study period.

The study reported an insignificant decrease in MCV among the Egypt group (83.78 fL) compared to Sudan (84.38 fL), P-value (0.656). This finding was consistent with Jasmina Pluncevic Gligoroska et al (2019) ²², who reported a Mean Cell Volume (MCV) of 84.45 fL among children under 12 years of age. Data are also consistent with Shuchismita Behera et al (2016) ²³, who reported an MCV of 84.3 fL among school-aged children (6-12y) in Odisha, India. The study reported a significant decrease in MCH in unadjusted analysis among Egypt group (27.61 pg) compared to Sudan (28.68 pg), P-value (0.020). However, after multivariable adjustment for age and gender (ANCOVA), this difference was no longer statistically significant (adjusted P-value 0.080). This finding was in line with Tariq E. Elmissbah (2024) ²¹ who reported low MCH of 27.0 pg among Sudanese primary school students, and with Jasmina Pluncevic Gligoroska et al (2019) ²² who reported MCH of 27.6 pg among children in Macedonia which represent the lower limit of the normal range, and data also consistent with I Achouri et al (2015) ²⁴, who reported significant decreased MCH (26.6).

The study reported an insignificant decrease in MCHC among the Egypt group (32.35 g/dl) compared to Sudan (32.64 g/dl), P-value (0.181). This finding was consistent with Shuchismita Behera et al ²³ who reported low MCHC (32.0) among children in Odisha, India, and Tariq E. Elmissbah (2024) ²¹ who concluded low mean MCHC of 32.5 among primary school students aged between 6–14 y in Khartoum, Sudan, and Jasmina Pluncevic Gligoroska et al (2019) ²² who reported low MCHC was 32.7 among children in Macedonia.

RDW showed a significant decrease among Egypt group (14.05%) compared to Sudan (14.88%), P-value (0.003), this finding was in line with Mabrouk et al (2022) ²⁵, who

reported a low RDW mean among school aged from 6–12 year in Beni- Suef, Egypt (mean 13.3). These results reinforce the use of RDW as an early hematological marker for detecting nutritional deficiencies before overt anemia develops, and the data also show that many studies have not investigated RDW compared to other RBC indices, especially among this population.

The study concluded a significant increase in platelet count (PLT) mean among the Egypt group ($289.26 \times 10^3/\mu\text{L}$) compared to Sudan ($214.80 \times 10^3/\mu\text{L}$), p-value (<0.001); this finding was in line with Oberoi Tania et al (2016) ²⁶, who reported an increase in platelet count in 24.5% of children in Odisha, India. The data were also consistent with Amna Gouda Mabrouk et al (2022) ²⁵, who reported an increase in platelet count among anemic children compared to the non-anemic children in Beni- Suef, Egypt (272,100 and 264,700), respectively.

The study reported a significant increase in TWBCs in the unadjusted analysis among the Egypt group ($6.09 \pm 2.05 \times 10^3/\mu\text{L}$) compared to Sudan ($5.42 \pm 1.54 \times 10^3/\mu\text{L}$), P-value (0.045). However, after adjustment for age and gender (ANCOVA), this difference retained a borderline trend toward significance (adjusted P-value 0.056). This finding was in line with Ahmed et al (2015) ²⁷, who reported a significant difference in TWBC count.

The study reported a significant increase in lymphocyte count among the Egypt group (40.17%) compared to Sudan (33.60%), P-value (<0.001). This finding was in line with Butsabong Lerkvaleekul et al ²⁸, who described a significant increase in lymphocytes (CD8 T-lymphocytes, CD19+ B-cells, and NK cells in children aged 5–10 years in school in Thailand.

The study reported a significant increase in Monocyte count among the Egypt group (8.89%) compared to Sudan (4.80%), P-value (<0.001).

Most of the observed differences persisted after multivariable adjustment for age and gender (Table 2), although MCH (adjusted p = 0.080) and TWBC (adjusted p = 0.056) no longer reached significance. Country of residence therefore appears to be independently associated with several, but not all, of the hematological variations observed.

The study reported a significant decrease in Eosinophil count among the Egypt group (1.50%) compared to Sudan (2.94%), P-value (<0.001). The study reported a significant increase in Serum iron among the Egypt group (116.99 $\mu\text{g/dL}$) compared to the Sudan group

(77.94 µg/dL), P-value (<0.001). However, both means were within the normal reference range, so this difference is unlikely to indicate iron deficiency in either group. Although fewer studies targeted serum iron levels compared to ferritin, iron depletion is a slow, multi-stage mechanism that depends on the rate of blood/iron loss; it takes months to years to completely deplete the body's iron stores. Serum iron, described as one of the last iron markers, drops during the progression, which may clarify the increased level in the Egypt group compared to Sudan, in addition to the wide range of normal serum iron among children (both groups were within the normal range). The study reported an insignificant decrease in serum B12 among the Egypt group (466.56 pg/mL) compared to Sudan (469.80 pg/mL), P-value (0.927). This finding was in line with Gil Prieto R et al. (2008)²⁹, who reported serum vitamin B12 percentiles in Spanish schoolchildren aged 13–15 years, with median values comparable to the means observed in both of our groups.

Limitations

Assessing full minerals and vitamins could offer a comprehensive view of hematological status, including nutritional parameters; in the study, some investigations were not assessed, such as folate, vitamin C, and ferritin, due to limited resources.

Furthermore, a key limitation of this study is the multi-center analytical design, as specimens were analyzed in separate laboratories in Sudan and Egypt. Although identical instrument models (Sysmex KX-21 and AutoLumo A1000) and standardized operational protocols were utilized, inter-laboratory variations such as subtle differences in reagent lot numbers, calibration frequency, storage temperature, precise time-to-analysis, and internal/external quality assurance parameters could not be fully controlled. Additionally, pre-analytical variables including the exact time of blood sampling within that window and participant fasting status were not systematically standardized, which represents a potential source of variance, as serum iron is subject to appreciable within-individual biological variation and is influenced by recent dietary intake and time of collection³⁰.

The two groups also differed significantly in age (12.21 ± 2.76 vs 10.48 ± 3.41 years, $p = 0.004$) and in gender distribution. Although both were adjusted for by ANCOVA, residual confounding cannot be excluded. Recruitment was limited to a single school in each

country and the achieved response rate was 53.6%, so the findings may not be generalizable to all displaced Sudanese schoolchildren. Dietary, socioeconomic and parasitological data were not collected, and ferritin, transferrin saturation and C-reactive protein were not measured, so iron status could not be fully characterized. Finally, the cross-sectional design permits the description of associations but does not allow causal inference.

Conclusion

The study showed hematological and micronutrient differences between the two groups, particularly a significant decrease in MCH, RDW, and eosinophils, but showed significant increased Platelets, TWBCs, Lymphocytes, monocytes, and serum iron. No significant morphological changes were observed, and vitamin B12, hemoglobin, MCV and MCHC remained comparable between the two groups.

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Conflict of Interest

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Use of Artificial Intelligence

During the preparation of this manuscript, the authors used ChatGPT (OpenAI, version GPT-4o) between June 2026 and August 2026 solely for language editing, improving readability, and English grammar refinement. The tool was not used to collect, analyze, or interpret raw biological data, nor to generate scientific conclusions. Following the use of this service, the authors reviewed, edited, and validated all content and take full responsibility for the integrity and accuracy of the published work.

ORCID iDs

Albara Ahmed <https://orcid.org/0000-0003-3245-7585>



Fatima Yousef Abdalla Alshaikh

<https://orcid.org/0009-0007-2165-3018>

Mohamed Elfatih Abdelwadoud

<https://orcid.org/0000-0003-3093-7585>

Availability of Data

The data supporting the findings of the present study are accessible through the corresponding author for research and humanitarian purposes.

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