ANEMIA AND HEMOGLOBIN CONCENTRATIONS AND THEIR ASSOCIATION WITH MINIMUM DIETARY DIVERSITY AMONG ADOLESCENTS AGED 15-19 IN INDIA

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by

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ABSTRACT

Background: Adolescence, from age 10 to 19 years, is a critical period for peak physical growth and development, but also a vulnerable time for nutritional deficiencies, including anemia. Preventing and treating anemia during adolescence is crucial for optimal health outcomes. The objective of this study was to: (1) determine the prevalence and correlates of anemia, and (2) examine whether minimum dietary diversity (MDD) is associated with anemia among adolescents aged 15-19 years in India.

Methods: This cross-sectional study used data from the Comprehensive National Nutrition Survey (CNNS) 2016-2018, which included sociodemographic, anthropometric, and dietary information from a nationally representative sample of Indian adolescents aged 15-19 years (n=6780). Logistic and linear regressions were used to identify correlates and also examine the associations of anemia and hemoglobin (Hb) concentrations with MDD, respectively. Sex-stratified analyses were also performed.

Results: Anemia was widely prevalent (33%), with significantly higher rates in females (47.5%) compared to males (18.0%). Being a member of the scheduled tribes was associated with higher odds of anemia and lower Hb concentrations both in total population and sex-stratified analyses. In the total population only, iron folic acid (IFA) supplementation and starchy staples consumption were associated with higher odds of anemia and lower Hb concentrations, while consumption of meat, poultry, fish, and aerated drinks were associated with lower odds of anemia and higher Hb concentrations. In males, anthropometric status <-2SD for body mass index-for-age z-score (BMIZ), mid-upper arm circumference-for-age z-score (MUACZ), and waist circumference z-score (WCZ) were associated with higher odds of anemia and lower Hb concentrations, while highest wealth index was associated with lower odds of anemia and higher Hb concentrations. In females, consumption of dairy was associated with higher odds of anemia and lower Hb concentrations. Meeting MDD was significantly associated with lower odds of anemia in males (unadjusted analysis), and higher Hb concentrations in females (adjusted analysis).

Conclusion: Our findings suggest that there are sex-specific risk factors for anemia, which may require tailored interventions. Promoting a diverse diet may help improve Hb concentrations among some adolescents. These findings underscore the need for comprehensive, tailored interventions to address the complex, multifaceted factors associated with anemia and lower Hb concentrations among adolescents in India.

BIOGRAPHICAL SKETCH

Mochammad Rizal completed his Diploma III and Bachelor of Science degree in Nutritional Sciences at Poltekkes Kemenkes Surabaya and Universitas Airlangga, Indonesia, respectively. He was awarded the Indonesia Endowment Fund for Education (LPDP) scholarship, enabling him to pursue a Master's degree in Nutritional Sciences with a specialization in human nutrition evidence for policy making at Cornell University. Rizal has been privileged to work with Dr. Saurabh Mehta. He is also grateful to Dr. Patricia Cassano for serving on his thesis committee. Before attending Cornell, he worked in multiple nutrition-related fields, from national sports institutions to non-governmental organizations. Rizal looks forward to joining a PhD program in Fall 2024 to continue his academic and research journey.

Dedicated to Allah SWT, and with the utmost gratitude and love to my father, Iswan Winarto, and my mother, Anik Nadhifah, whose unwavering love and support have been my source of strength and inspiration throughout my academic journey.

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LIST OF ABBREVIATIONS

BMI	: body mass index
BMIZ	: BMI-for-age z-score
CI	: confidence interval
CNNS	: Comprehensive National Nutrition Survey
DMLT	: Diploma in Medical Laboratory Technology
FAO	: Food and Agriculture Organization
FFQs	: food frequency questionnaires
HAZ	: height-for-age z-score
Hb	: hemoglobin
IDA	: iron deficiency anemia
IFA	: iron folic acid
IRB	: Institutional Review Board
Kg	: kilogram
MDD	: minimum dietary diversity
mm	: milimeter
MUAC	: mid-upper arm circumference
MUACZ	: mid-upper arm circumference -for-age z-score
NFHS	: National Family Health Survey
OR	: odds ratio

PGIMER : Post Graduate Institute for Medical Education and Research

PPS : probability proportional to size

RBCs : red blood cells

SD : standard deviation

SSFT : subscapular skinfold thickness

SSFTZ : subscapular skinfold thickness z-score

TSFT : triceps skinfold thickness

TSFTZ : triceps skinfold thickness z-score

WC : waist circumference

WCZ : waist circumference z-score

WHO : World Health Organization

WRA : women of reproductive age

INTRODUCTION

Anemia is a medical condition characterized by a low concentrations of hemoglobin (Hb) or hematocrit. Hb is an iron-containing protein responsible for transporting oxygen (O_2) from the lungs to the body's tissues through arteries (1). Hb also delivers carbon dioxide (CO_2) from tissues back to the lungs through veins. The concentration of Hb is measured in grams per deciliter (g/dl), and the general minimum concentrations for a healthy individual varies between 11-18 g/dl, depending on age group and adjusted for sex, smoking status and elevation (2). A low concentrations of Hb may result in a low concentrations of O_2 in the body. Therefore, a sufficient Hb concentrations must be maintained to ensure adequate tissue oxygenation for the body to function properly (3).

Anemia develops from any condition that lowers red blood cells (RBCs) in the bloodstream, which can result from decreased erythropoiesis, increased hemolysis, or excessive blood loss (4). The cause of anemia is classified as either non-nutritional or nutritional causes. Non-nutritional causes include genetic blood disorders, hemoglobinopathies, inflammation, infectious diseases and other physiological conditions such as menstruation and pregnancy (4–8).

Nutritional anemia is more widely prevalent, and is most commonly caused by iron deficiency, termed iron deficiency anemia (IDA) (4). However, deficiencies in folate, vitamin B12 and vitamin A deficiencies can also cause anemia (2).

The prevalence of anemia, which poses a major public health issues, is highest in low- and middle-income countries. Women and children are at high-risk of anemia due to a combination of factors such as inadequate dietary intake of iron, folate, and vitamin B12, as well as infections like malaria, hookworm infestations, and schistosomiasis. Additionally, pregnancy and lactation can increase the demand for iron, leading to an increased risk of anemia in women of reproductive age (WRA). In 2019, approximately 840 millions WRA and children aged 6-59 months worldwide were affected by anemia (9). This prevalence increased by 40 million since 2011 as reported by the World Health Organization (WHO) (10). In adolescent, anemia affected 24% of adolescents globally in 2016, or approximately 430 millions, up from 357 millions in 1990 (11).

Anemia is considered as a moderate public health problem among adolescents in India. The Comprehensive National Nutrition Survey (CNNS) 2019 has shown that 28% adolescents aged 10-19 years were anemic (12). The consequences of anemia are serious, including impacts on human capital development, increased morbidity and mortality, impaired cognition, and decreased physical work capacity (5). Adolescence is a critical time for intervention and prevention of anemia, as this is a particularly nutrient-sensitive time for maturation, including the expansion of red blood cell mass and muscle mass. Female adolescents are at a higher risk of iron deficiency due to the onset of menstruation coinciding with the growth and maturation process (13). The daily requirement of iron increases from 0.7-0.9 mg/day during pre-adolescence to as much as 2.2 mg/day in adolescents aged 10-19 years (14). Failing to address anemia during this time can perpetuate the cycle of intergenerational anemia.

Food consumption plays a crucial role in the development of nutritional anemia (15,16). Dietary diversity, or the intake of a variety of foods from multiple food groups, is needed to meet nutrient requirements and may help to reduce the risk of nutritional anemia (17–19). In low- and middle income countries, including India, diets are often lacking in variety and consist mainly of starchy staples and plant-based protein sources, with limited consumption of animal-source foods (ASF), fruits, and vegetables (20–22). A diet based mostly on cereal products increases the risk of iron deficiency due to the high content of iron inhibitors, such as phytic acid, in the diets (23). It is also worth noting that the type of iron found in plant-based foods is non-heme iron, which is less readily absorbed by the body than the heme iron found in ASF. Therefore, consuming more ASF and fruits and vegetables rich in vitamin C and carotenoids can enhance iron absorption from cereal-based diets (24). ASF also plays an important role in reducing anemia risk by providing highly bioavailable heme iron, vitamin B12, and vitamin A (5,25).

The relationship between dietary diversity and anemia and Hb concentrations remain mixed. While some studies suggest an association between dietary diversity and iron status (22,26–30), others showed no link between dietary diversity and anemia (31–33). Additionally, the aforementioned studies mostly investigate pregnant women and WRA population, with limited data available for adolescents. Furthermore, despite the abundance of nutrition data for children younger than five years, limited research has been conducted on adolescents, and there are no global nutrition targets for this age group (34).

The objective of this study was to: (1) determine the prevalence and correlates of anemia, and (2) examine whether minimum dietary diversity (MDD) is associated with anemia among adolescents aged 15-19 years in India. While the CNNS dataset covered a broader age range of 10-19 years, we decided to narrow our focus to the 15-19 year age group to allow for a more in-depth analysis. This age group has been found to have a higher prevalence of anemia than the younger age group of 10-14 years, as well as a wider sex disparity in anemia prevalence. In the 10-14 year age range, the gap in anemia prevalence between males and females was only 15 percentage points (17% for males vs. 32% for females), whereas in the 15-19 year age range, the gap widened to 30 percentage points, with females experiencing anemia at a rate more than twice that of males (18% for males vs. 48% for females). This suggests that the factors contributing to anemia in this older age group may differ significantly between males and females and warrant further investigation.

METHODS

Study Population

This cross-sectional analysis used data from the CNNS 2016-2018 in India. Data included in the current analysis were adolescents aged 15-19 years. The survey details had been described elsewhere (12). In brief, the CNNS was conducted using a multi-stage, stratified, probability proportional to size (PPS) sampling to representatively select samples of households and individuals aged 0-19 years across the 30 states of India. A total of 112,316 interviews and anthropometric data and 51,029 biological samples were collected from rural and urban areas during the survey period.

Data Collection

Sociodemographic and Dietary Interviews

Questionnaires were administered to the adolescents using English and/or one of the 20 state-specific languages translated by qualified professionals as appropriate. Sociodemographic variables included in the study were adolescents' schooling status, Mother education, religion, caste/tribe, residence, wealth index, consumption of iron folic acid (IFA) supplements in the last week, and consumption of deworming tablets in the last six months. Dietary information was assessed using daily and seven-day, non quantitative, food frequency questionnaires (FFQs) on the consumption of a variety of food groups. The interviewers were university graduates with experience in survey data collection and were trained for two weeks and tested before conducting the interviews. The interviewers were assigned to respondents with the same sex to create a comfortable environment for answering potentially sensitive questions. The survey involved a rigorous three-tier monitoring system for data quality assurance (12).

Anthropometric Assessment

Weight was measured lightly clothed using electronic digital scales (SECA, Germany) to the nearest 0.1 kilogram (kg). Height was measured standing using three-piece wooden height boards. The instruments were set on a flat portable wooden square with a spirit level to ensure a level surface for weight and height measurement. Mid-upper arm circumference (MUAC) was measured in the middle-upper arm with standard pressure using MUAC tape. Triceps skinfold thickness (TSFT) and subscapular skinfold thickness (SSFT) were measured using skinfold calipers (Holtain, United Kingdom). Waist circumference (WC) was measured using fiberglass tape after participants exhaled to prevent muscle contraction. All measurements (MUAC, TSFT, SSFT, and WC) were taken to the nearest 1 millimeter (mm).

Anthropometric measurements were performed by two trained anthropometrists who passed the standardization test. All measurements were performed twice and averaged except for weight which was only measured once. The results were recorded manually on the specific data collection form and entered electronically using a data entry application. All of the instruments were checked and calibrated daily before data collection. Tape was regularly replaced when no longer in adequate condition to make an accurate measurement.

Assessment of Blood Samples

Blood samples were collected using systematic random sampling. Blood samples were obtained from participants in the morning following anthropometric measurement and taken only after consent and interview was completed. Approximately 10 milliliters (ml) of blood was collected in vacutainer tubes. Sample handling and storage had been described in detail following standard procedures prior to laboratory analyses (12). Hb concentrations were measured by photometric estimation using cyanmethemoglobin technique or using a 5 parts automated cell counter (Beckman Coulter, United States). Blood samples were collected by experienced phlebotomists who were qualified with a Diploma in Medical Laboratory Technology (DMLT).

Ethical Approvals

Ethical approval was obtained from the Population Council's Institutional Review Board (IRB) in New York and the ethics committee of Post Graduate Institute for Medical Education and Research (PGIMER) in Chandigarh. For adolescents aged 15-17 years, written informed consent was obtained from their caregivers and written informed assent obtained from the participants. Adolescents aged 18-19 years provided their own consent.

Definition of Variables

The main exposure of interest was MDD, which was defined as "yes" and "no". The Food and Agriculture Organization (FAO) guideline was adapted to measure individual dietary diversity scores. While the FAO used a 24-hour recall method to aggregate foods into nine groups (35), the CNNS only employed a non-quantitative FFQ to collect dietary information. Adolescents who consumed foods from four or more food groups at least seven times a week were considered to meet the MDD, while those who consumed less than four food groups seven times a week were considered not to meet the MDD.

These nine food groups included daily consumption of starchy staples, pulses (including beans, peas, and lentils), nuts and seeds, dark green leafy vegetables, other vegetables, fruits, dairy, eggs, and meat (including poultry and fish). Additionally, consumption of food groups to be avoided were also measured, including junk foods, fried foods, sweets, and aerated drinks. The avoidable food groups were defined as “yes” (≥3x per week) and “no” (<3x per week).

To assess covariates, information on several sociodemographic variables and anthropometric status were collected. Self reported sociodemographic information assessed included schooling status (defined as “currently in school” and “not in school”), mother's education (defined as “≤8 years” and “>8 years”, based on eight years of formal schooling required for elementary education), religion (defined as “Hindu” and “others”), caste/tribe (defined as “scheduled caste”, “scheduled tribe”, “other backward class”, and “non-backward class”), residence (defined as “rural” and “urban”), and wealth index (defined as “lowest”, “low”, “middle”, “high”, and “highest”). Participants were also asked about IFA supplement consumption in the last week and consumption of deworming tablets in the last six months; affirmative responses were reported as “yes” compared to “no/do not know”.

Anthropometric parameters were also assessed in this study. Height-for-age *z*-score (HAZ), BMI-for-age *z*-score (BMIZ), mid-upper arm circumference-for-age *z*-score (MUACZ), triceps skinfold thickness *z*-score (TSFTZ), subscapular skinfold thickness *z*-score (SSFTZ), and waist circumference z-score (WCZ) were calculated using the WHO international growth reference data for 5-19 years (36). HAZ and MUACZ were defined as <-2 standard deviation (SD) and normal (-2SD to +2SD), while those for BMIZ, TSFTZ, SSFTZ, and WCZ were defined as <-2SD, normal (-2SD to +2SD), and >+2SD.

The main outcome of this study was anemia, which was categorized into anemic and non-anemic. Anemia was defined as Hb concentrations <13.0 g/dl for male and <12.0 g/dl for female, as recommended by WHO (2). Hb concentrations were also analyzed as a continuous variable as the second outcome.

Statistical Analyses

All analyses were conducted for the total population and also stratified by sex. Sample weights for national level and biological domain of analysis were considered for all analyses. Descriptive analyses were reported for anemia status, sociodemographic characteristics, anthropometric status, and dietary information as categorical variables (n, %).

Logistic and linear regressions were performed to examine the associations between dietary diversity with categorical anemia variable and continuous Hb concentrations variable, respectively. Logistic regression was used to estimate odds ratio (OR) and 95% confidence interval (CI) for anemia. Linear regression was used to measure change in effect point estimates (β) and 95% CI for the Hb concentrations.

The effects of meeting MDD on anemia and Hb concentrations and the role of other covariates as potential confounders were calculated from the percent change in β between unadjusted and adjusted analyses. Each correlate of anemia and Hb concentrations with $p<0.20$ from univariate analysis were individually added to the models to generate adjusted β of meeting MDD on anemia and Hb concentrations. Correlates that changed the β by >10% were considered as potential confounders (37) and were included in the final models for anemia and Hb concentrations.

Final linear models were checked for normality using normality of residual (histogram and Q-Q plots), collinearity (variance inflation factors), and homoscedasticity (residual vs. predicted plots). The final logistic regression models were evaluated using the goodness-of-fit test. SAS software version 9.4 was used to conduct the statistical analysis (SAS Institute, Cary, NC).

RESULTS

Population Characteristics

Characteristics of the adolescent's population aged 15-19 years in India are presented in Table 1. Anemia status data were available for 6,780 of the 17,442 weighted samples in the CNNS. Of the 6,780 individuals, 3,372 were male and 3,408 were female. Thirty-three percent of the total population was anemic. A higher proportion of females were found to be anemic (n=1,619, 47.5%) compared to males (n=616, 18.3%).

The majority of both males and females were currently in school, had mothers with fewer than 8 years of education, followed Hinduism, belonged to the other backward class, and resided in rural areas. The majority of the population reported not taking IFA supplements and deworming tablet or do not know whether they consume those supplements and tablet.

A larger proportion of <-2SD HAZ and MUACZ was higher in the anemic group compared to the non-anemic group. In males, the proportion of BMIZ <-2SD and WCZ <-2SD in the anemic group was higher compared to the non-anemic group. Conversely, in females the proportion of BMIZ <-2SD and WCZ <-2SD in the anemic group was lower compared to the non-anemic group. In addition, in male, SSFTZ <-2SD was higher in the anemic compared to the non-anemic group, while this proportion was similar in female.

Dietary variables are presented in Table 2. The overall results showed that the majority of adolescents aged 15-19 years in India did not meet the daily consumption criteria of nine food groups. Anemic adolescents had a higher daily consumption of starchy staples compared to the non-anemic adolescents. Anemic males had lower daily consumption of dairy (40.5%) compared to non-anemic males (49.1%). Conversely, anemic females had a higher daily consumption of dairy (52.4%) compared to non-anemic females (41.8%). In addition, daily consumption of pulses (beans, peas, lentils), nuts and seeds, dark green leafy vegetables, other vegetables, fruits, eggs, and meat poultry and fish were similar between anemic and non-anemic group.

The proportion of males consuming fried foods and aerated drinks at least three times a week were lower in the anemic group compared to the non-anemic group (15.2% vs. 18.8% and 5.8% VS. 10.1%, respectively). However, the proportion of females consuming fried foods at least three times a week was higher in the anemic group (13.1%) compared to the non-anemic group (9.7%). The proportion of other food groups generally suggested to be minimized or avoided (junk foods and sweets in all groups, and aerated drinks in females) were similar between anemic and non-anemic groups. In terms of meeting MDD (at least consuming four out of nine food groups), the proportion of meeting MDD in males was lower in the anemic group (3.3%) compared to the non-anemic group (7.1%). In contrast, this proportion was almost similar between anemic group and non-anemic group (7.0% and 7.8%, respectively) in females.

Table 1. Population characteristics of participants of adolescents aged 15-19 years in the CNNS data

Variables	Total population			Male			Female		
	N	Anemic, n (%)	Non anemic, n (%)	N	Anemic, n (%)	Non anemic, n (%)	N	Anemic, n (%)	Non anemic, n (%)
Anemia status	6780	2237 (33.0)	4543 (67.0)	3372	616 (18.3)	2756 (81.7)	3408	1619 (47.5)	1789 (52.5)
Sociodemographic									
Schooling status	6780	2235	4545	3372			3408		
Currently in school		2101 (94.0)	4306 (94.7)		595 (96.7)	2631 (95.5)		1506 (93.0)	1674 (93.6)
Not in school		134 (6.0)	239 (5.3)		20 (3.3)	125 (4.5)		113 (7.0)	114 (6.4)
Mother education	6766			3365			3401		
≤8 years		1894 (84.8)	3793 (83.7)		510 (83.0)	2258 (82.1)		1383 (85.6)	1535 (86.0)
>8 years		338 (15.2)	740 (16.3)		104 (17.0)	491 (17.9)		233 (14.4)	249 (14.0)
Religion	6780			3372			3408		
Hindu		1806 (80.8)	3772 (83.0)		501 (81.4)	2309 (83.8)		1304 (80.5)	1463 (81.8)
Others		429 (19.2)	772 (17.0)		114 (18.6)	447 (16.2)		315 (19.5)	325 (18.2)
Caste/Tribe	6630			3290			3340		
Scheduled caste		580 (26.6)	983 (22.1)		164 (27.7)	586 (21.7)		416 (26.3)	396 (22.6)
Scheduled tribe		291 (13.4)	368 (8.3)		106 (17.9)	239 (8.9)		184 (11.7)	128 (7.3)
Other backward class		817 (37.5)	2051 (46.1)		184 (31.1)	1274 (47.3)		633 (39.9)	776 (44.3)
Non-backward class		489 (22.5)	1049 (23.6)		138 (23.3)	596 (22.1)		351 (22.2)	452 (25.8)
Residence	6780			3372			3408		
Rural		1659 (74.2)	3304 (72.7)		479 (77.8)	1967 (71.4)		1180 (72.9)	1337 (74.7)
Urban		576 (25.8)	1241 (27.3)		136 (22.2)	789 (28.6)		439 (27.1)	451 (25.3)
Wealth index	6780			3372			3408		
Lowest		424 (19.0)	679 (15.0)		128 (20.8)	533 (19.3)		296 (18.3)	310 (17.3)
Low		422 (19.0)	864 (19.0)		140 (22.8)	370 (13.4)		282 (17.4)	330 (18.5)
Middle		481 (21.5)	969 (21.3)		147 (23.9)	568 (20.6)		334 (20.6)	401 (22.4)
High		531 (23.8)	1019 (22.4)		116 (18.8)	629 (22.8)		415 (25.6)	390 (21.8)
Highest		376 (16.8)	1014 (22.3)		84 (13.7)	656 (23.8)		292 (18.0)	358 (20.0)
IFA supplements	6780			3372			3408		
Yes		176 (7.9)	263 (5.8)		44 (7.3)	121 (4.4)		131 (8.1)	142 (8.0)
No/do not know		2059 (92.1)	4281 (94.2)		571 (92.7)	2635 (95.6)		1488 (91.9)	1646 (92.0)
Deworming tablet	6780			3372			3408		
Yes		406 (18.2)	746 (16.4)		102 (16.6)	394 (14.3)		304 (18.8)	352 (19.7)
No/do not know		1829 (81.8)	3799 (83.6)		513 (83.4)	2362 (85.7)		1315 (81.2)	1436 (80.3)
Anthropometric status									
HAZ	6780			3372			3408		
<-2SD		933 (41.8)	1686 (37.1)		262 (42.6)	988 (35.9)		671 (41.5)	697 (39.0)
Normal		1302 (58.2)	2859 (62.9)		353 (57.4)	1768 (64.1)		947 (58.5)	1091 (61.0)
BMIZ	6780			3372			3408		
<-2SD		703 (31.5)	1531 (33.7)		314 (51.0)	1028 (37.3)		389 (24.1)	502 (28.1)
Normal		1518 (67.9)	2980 (65.6)		299 (48.6)	1703 (61.8)		1219 (75.3)	1277 (71.4)
>+2SD		13 (0.6)	34 (0.8)		2 (0.3)	25 (0.9)		10 (0.7)	8 (0.5)

Variables	Total population			Male			Female		
	N	Anemic, n (%)	Non anemic, n (%)	N	Anemic, n (%)	Non anemic, n (%)	N	Anemic, n (%)	Non anemic, n (%)
MUACZ	6780			3372			3408		
<-2SD		783 (35.0)	1543 (33.9)		361 (58.7)	1125 (40.8)		421 (26.0)	417 (23.3)
Normal		1452 (65.0)	3002 (66.1)		254 (41.3)	1631 (59.2)		1198 (74.0)	1371 (76.7)
TSFTZ	6780			3372			3408		
<-2SD		196 (8.8)	305 (6.7)		20 (3.4)	87 (3.2)		175 (10.8)	218 (12.2)
Normal		2039 (91.2)	4236 (93.2)		594 (96.6)	2667 (96.7)		1444 (89.2)	1570 (87.8)
>+2SD		0 (0.0)	3 (0.1)		0 (0.0)	2 (0.1)		0 (0.0)	0 (0.0)
SSFTZ	6780			3372			3408		
<-2SD		91 (4.1)	128 (3.0)		38 (6.2)	76 (2.8)		52 (3.3)	62 (3.5)
Normal		2144 (95.9)	4402 (96.8)		577 (93.8)	2676 (97.1)		1566 (96.7)	1726 (96.5)
>+2SD		0 (0.0)	5 (0.1)		0 (0.0)	4 (0.2)		0 (0.0)	0 (0.0)
WCZ	6780			3372			3408		
<-2SD		614 (27.5)	1061 (23.4)		215 (35.1)	582 (21.1)		398 (24.6)	478 (26.8)
Normal		1621 (72.5)	3481 (76.6)		400 (64.9)	2172 (78.8)		1221 (75.4)	1309 (73.2)
>+2SD		0 (0.0)	2 (0.1)		0 (0.0)	1 (0.1)		0 (0.0)	1 (0.1)

Note: data are presented as weighted samples

Table 2. Adolescents' daily intakes presented by food groups and dietary diversity

Variables	Total population			Male			Female		
	N	Anemic, n (%)	Non anemic, n (%)	N	Anemic, n (%)	Non anemic, n (%)	N	Anemic, n (%)	Non anemic, n (%)
Daily consumption of food groups									
Starchy staples	6780			3372			3408		
Yes		598 (26.8)	942 (20.7)		127 (20.6)	500 (18.2)		471 (29.1)	442 (24.7)
No		1637 (73.2)	3602 (79.3)		489 (79.4)	2256 (81.8)		1148 (70.9)	1347 (75.3)
Pulses: beans peas, lentils	6780			3372			3408		
Yes		535 (24.0)	1078 (23.7)		144 (23.4)	586 (21.3)		391 (24.2)	490 (27.4)
No		1700 (76.0)	3468 (76.3)		471 (76.6)	2170 (78.7)		1228 (75.8)	1298 (72.6)
Nuts and seeds	6780			3372			3408		
Yes		107 (4.8)	192 (4.2)		16 (2.7)	120 (4.4)		91 (5.6)	71 (4.0)
No		2128 (95.2)	4352 (95.8)		599 (97.3)	2635 (95.6)		1528 (94.4)	1717 (96.0)
Dark green leafy vegetables	6780			3372			3408		
Yes		442 (19.8)	863 (19.0)		101 (16.4)	444 (16.1)		341 (21.1)	419 (23.4)
No		1793 (80.2)	3682 (81.0)		514 (83.6)	2312 (83.9)		1278 (78.9)	1369 (76.6)
Other vegetables	6780			3372			3408		
Yes		361 (16.2)	361 (16.1)		68 (11.1)	338 (12.3)		292 (18.1)	391 (21.9)
No		1874 (83.8)	1874 (83.9)		547 (88.9)	2418 (87.7)		1326 (81.9)	1397 (78.1)
Fruits	6780			3372			3408		
Yes		188 (8.5)	398 (8.8)		50 (8.2)	263 (9.5)		138 (8.6)	135 (7.6)
No		2046 (91.5)	4147 (91.2)		565 (91.8)	2493 (90.5)		1481 (91.4)	1653 (92.4)
Dairy	6780			3372			3408		
Yes		1098 (49.1)	2103 (46.3)		249 (40.5)	1355 (49.1)		847 (52.4)	748 (41.8)
No		1138 (50.9)	2442 (53.7)		366 (59.5)	1402 (50.9)		771 (47.6)	1040 (58.2)
Eggs	6780			3372			3408		
Yes		39 (1.8)	125 (2.8)		8 (1.3)	100 (3.6)		30 (1.9)	25 (1.4)
No		2196 (98.2)	4419 (97.2)		607 (98.7)	2656 (96.4)		1588 (98.1)	1763 (98.6)
Meat poultry and fish	6780			3372			3408		
Yes		0 (0.0)	20 (0.4)		0 (0.0)	20 (0.7)		0 (0.0)	0 (0.0)
No		2235 (100.0)	4525 (99.6)		616 (100.0)	2736 (99.3)		1619 (100.0)	1789 (100.0)
Junk foods (≥3x/week)	6780			3372			3408		
Yes		68 (3.1)	204 (4.5)		29 (4.7)	151 (5.5)		39 (2.4)	53 (3.0)
No		2167 (96.9)	4340 (95.5)		586 (95.3)	2605 (94.5)		1580 (97.6)	1735 (97.0)
Fried foods (≥3x/week)	6780			3372			3408		
Yes		305 (13.7)	690 (15.2)		93 (15.2)	518 (18.8)		211 (13.1)	172 (9.7)
No		1930 (86.3)	3854 (84.8)		522 (84.8)	2238 (81.2)		1408 (86.9)	1616 (90.3)
Sweets (≥3x/week)	6780			3372			3408		
Yes		131 (5.9)	256 (5.6)		44 (7.2)	196 (7.1)		87 (5.4)	59 (3.3)
No		2104 (94.1)	4289 (94.4)		572 (92.8)	2559 (92.9)		1532 (94.6)	1729 (96.7)

Variables	Total population			Male			Female		
	N	**Anemic, n (%)**	**Non anemic, n (%)**	**N**	**Anemic, n (%)**	**Non anemic, n (%)**	**N**	**Anemic, n (%)**	**Non anemic, n (%)**
Aerated drinks (≥3x/week)	6780			3372			3408		
Yes		78 (3.5)	316 (7.0)		35 (5.8)	278 (10.1)		42 (2.6)	38 (2.1)
No		2157 (96.5)	4228 (93.0)		580 (94.2)	2633 (89.9)		1577 (97.4)	1750 (97.9)
Minimum dietary diversity*	6780			3372			3408		
Yes		134 (6.0)	335 (7.4)		20 (3.3)	195 (7.1)		114 (7.0)	139 (7.8)
No		2101 (94.0)	4210 (92.6)		595 (96.7)	2561 (92.9)		1505 (93.0)	1649 (92.2)

Note: data are presented as weighted samples

* Adolescents who consumed foods from four or more of food groups daily were considered to meet the MDD, and those wo consumed less than four of food groups daily were considered to not meet the MDD

Correlates of Anemia and Hb Concentrations

Table 3 presents all univariate correlates of anemia. In the total population, caste/tribe (scheduled tribe, compared to other categories; OR: 1.70, 95% CI: 1.21, 2.37) and consuming IFA supplements (OR: 1.39, 95% CI: 1.01, 1.91) were significantly associated with higher odds of anemia ($p<0.05$). In males, caste/tribe (scheduled tribe; OR: 1.91, 95% CI: 1.15, 3.17), consuming IFA supplements (OR: 1.70, 95% CI: 1.01, 2.87), and anthropometric status <-2SD for BMIZ (OR: 1.74, 95% CI: 1.23, 2.45), MUACZ (OR: 2.06, 95% CI: 1.46, 2.91), SSFTZ (OR: 2.34, 95% CI: 1.18, 4.63), and WCZ (OR: 2.01, 95% CI: 1.36, 2.98) were significantly associated with higher odds of anemia, while residence (urban; OR: 0.71, 95% CI: 0.51, 0.99) and wealth index (highest; OR: 0.50, 95% CI: 0.30, 0.82) were significantly associated with lower odds of anemia. In females, caste/tribe (scheduled tribe; OR: 1.56, 95% CI: 1.18, 2.93) was associated with higher odds of anemia.

Daily consumption of starchy staples (OR: 1.40, 95% CI: 1.10, 1.78) was significantly associated with higher odds of anemia, while daily consumption of meat, poultry, and fish (OR: 0.00, 95% CI: 0.00, 0.01) as well as consumption aerated drinks at least three times a week (OR: 0.49, 95% CI: 0.31, 0.77) were associated with lower odds of anemia. In males, daily consumption of dairy (OR: 0.71, 95% CI: 0.50, 0.99), eggs (OR: 0.36, 95% CI: 0.13, 0.98), meat, poultry, and fish (OR: 0.00, 95% CI: 0.00, 0.01) and consumption of aerated drinks at least three times a week (OR: 0.55, 95% CI: 0.31, 0.97) were significantly associated with lower odds of anemia. In females, daily consumption of dairy (OR: 1.53, 95% CI: 1.17, 2.00) was significantly associated with higher odds of anemia.

Findings from the univariate correlates of Hb concentrations are presented in Table 4. Results in total population indicated that caste/tribe (scheduled tribe; β: -0.55, 95% CI: 0.-0.83, -0.27), consuming IFA supplements in the last week (β: -0.47, 95% CI: -0.79, -0.15) and deworming tablet in the last six months (β: -0.21, 95% CI: -0.38, -0.04), HAZ (<-2SD; β: -0.19, 95% CI: -0.37, -0.00), TSFTZ (<-2SD; β: -0.71, 95% CI: -1.06, -0.36), and WCZ (<-2SD; β: -0.24, 95% CI: -0.44, -0.04) were significantly associated with lower Hb concentrations, while mother's education (>8 years; β: 0.27, 95% CI: 0.04, 0.50), BMIZ (<-2SD; β: 0.29, 95% CI: 0.11, 0.48), and MUACZ (<-2SD; β: 0.19, 95% CI: 0.02, 0.37) were significantly associated with higher Hb concentrations.

In male adolescents, caste/tribe (scheduled caste; β: -0.19, 95% CI: -0.46, -0.08; and scheduled tribe; β: -0.72, 95% CI: -1.01, -0.42), consuming deworming tablet (β: -0.28, 95% CI: -0.46, -0.09), and anthropometric <-2SD for BMIZ (β: -0.25, 95% CI: -0.44, -0.05), MUACZ (β: -0.50, 95% CI: -0.68, -0.32), and WCZ (β: -0.47, 95% CI: -0.72, -0.23) were significantly associated with lower Hb concentrations, while wealth index (highest; β: 0.32, 95% CI: 0.09, 0.54) was significantly associated with higher Hb concentrations. In females, caste/tribe (scheduled tribe; β: -0.59, 95% CI: -0.91, -0.26) was the only factor significantly associated with lower Hb concentrations.

Daily consumption of starchy staples (β: -0.30, 95% CI: -0.51, -0.09) and other vegetables (β: -0.23, 95% CI: -0.45, -0.02) were significantly associated with lower Hb concentrations. In contrast, daily consumption of eggs (β: 0.67, 95% CI: 0.20, 1.14), meat, poultry, and fish (β: 0.64, 95% CI: 0.37, 0.91), as well as consumption of junk foods (β: 0.52, 95% CI: 0.22, 0.84), fried foods (β: 0.28, 95% CI: 0.01, 0.56), and aerated drinks (β: 0.86, 95% CI: 0.53, 1.19) at least three times a week were significantly associated with higher Hb concentrations.

In males, daily consumption of meat, poultry, and fish (β: -0.52, 95% CI: -0.79, -0.25) was the only factors significantly associated with lower Hb concentrations. In females, daily consumption of dairy (β: -0.22, 95% CI: -0.41, -0.02) and consumption of fried foods at least three times a week (β: -0.22, 95% CI: -0.41, -0.03) were significantly associated with lower Hb concentrations, while daily consumption of pulses (beans, peas, and lentils; β: 0.21, 95% CI: -0.00, -0.41) were significantly associated with higher Hb concentrations.

Table 3. Univariate correlates of anemia status of adolescents aged 15-19 years in the CNNS data

Variables	Total		Male		Female	
	OR (95% CI)	**p**	**OR (95% CI)**	**p**	**OR (95% CI)**	**p**
Sociodemographic						
Schooling status						
Not in school	Reference	0.56	Reference	0.46	Reference	0.76
Currently in school	0.87 (0.54, 1.40)		1.38 (0.58, 3.26)		0.90 (0.47, 1.74)	
Mother education						
≤8 years	Reference	0.46	Reference	0.76	Reference	0.80
>8 years	0.92 (0.72, 1.16)		0.94 (0.64, 1.38)		1.04 (0.78, 1.39)	
Religion						
Hindu	Reference	0.33	Reference	0.48	Reference	0.69
Others	1.16 (0.86, 1.57)		1.18 (0.75, 1.85)		1.09 (0.72, 1.64)	
Caste/Tribe						
Scheduled caste	1.27 (0.94, 1.70)	**<.01****	1.21 (0.76, 1.91)	**<.01****	1.35 (0.90, 2.04)	**0.03****
Scheduled tribe	1.70 (1.21, 2.37)		1.91 (1.15, 3.17)		1.56 (1.18, 2.93)	
Other backward class	0.85 (0.65, 1.12)		0.62 (0.41, 0.95)		1.05 (0.74, 1.50)	
Non-backward class	Reference		Reference		Reference	
Residence						
Rural	Reference	0.51	Reference	**0.05****	Reference	0.57
Urban	0.93 (0.73, 1.17)		0.71 (0.51, 0.99)		1.10 (0.79, 1.53)	
Wealth index						
Lowest	1.26 (0.86, 1.83)	**<.01****	1.33 (0.74, 2.39)	**<.01****	1.15 (0.70, 1.89)	**0.18***
Low	0.98 (0.72, 1.35)		1.01 (0.60, 1.72)		1.03 (0.67, 1.57)	
Middle	Reference		Reference		Reference	
High	1.05 (0.77, 1.43)		0.71 (0.43, 1.74)		1.28 (0.86, 1.90)	
Highest	0.75 (0.56, 0.99)		0.50 (0.30, 0.82)		0.98 (0.68, 1.41)	
IFA supplements						
No/do not know	Reference	**0.04****	Reference	**0.05****	Reference	0.92
Yes	1.39 (1.01, 1.91)		1.70 (1.01, 2.87)		1.02 (0.65, 1.60)	
Deworming tablet						
No/do not know	Reference	0.28	Reference	0.35	Reference	0.70
Yes	1.13 (0.91, 1.41)		1.19 (0.82, 1.73)		0.94 (0.70, 1.27)	
Anthropometric status						
HAZ						
<-2SD	1.22 (0.98, 1.52)	**0.08***	1.33 (0.94, 1.87)	**0.11***	1.11 (0.81, 1.51)	0.52
Normal	Reference		Reference		Reference	
BMIZ						
<-2SD	0.90 (0.73, 1.12)	0.54	1.74 (1.23, 2.45)	**<.01****	0.81 (0.61, 1.09)	0.32
Normal	Reference		Reference		Reference	
>+2SD	0.73 (0.31, 1.78)		0.46 (0.10, 2.10)		1.28 (0.46, 3.62)	
MUACZ						
<-2SD	1.05 (0.86, 1.28)	0.63	2.06 (1.46, 2.91)	**<.01****	1.16 (0.88, 1.52)	0.29
Normal	Reference		Reference		Reference	

Variables	Total		Male		Female	
	OR (95% CI)	**p**	**OR (95% CI)**	**p**	**OR (95% CI)**	**p**
TSFTZ						
<-2SD	1.34 (0.95, 1.88)		1.08 (0.52, 2.23)		0.87 (0.60, 1.28)	
Normal	Reference	**0.10***	Reference	0.84	Reference	0.49
>+2SD	N/A[a]		N/A[a]		N/A[a]	
SSFTZ						
<-2SD	1.36 (0.85, 2.16)		2.34 (1.18, 4.63)		0.94 (0.49, 1.81)	
Normal	Reference	0.20	Reference	**0.01****	Reference	0.85
>+2SD	N/A[a]		N/A[a]		N/A[a]	
WCZ						
<-2SD	1.24 (0.99, 1.57)		2.01 (1.36, 2.98)		0.89 (0.66, 1.21)	
Normal	Reference	**0.07***	Reference	**<.01****	Reference	0.46
>+2SD	N/A[a]		N/A[a]		N/A[a]	
Dietary						
Starchy staples						
No	Reference	**<.01****	Reference	0.41	Reference	**0.19***
Yes	1.40 (1.10, 1.78)		1.17 (0.81, 1.70)		1.25 (0.89, 1.75)	
Pulses: beans, peas, lentils						
No	Reference	0.91	Reference	0.59	Reference	0.30
Yes	1.01 (0.80, 1.29)		1.13 (0.93, 1.76)		0.84 (0.61, 1.16)	
Nuts and seeds						
No	Reference	0.49	Reference	**0.17***	Reference	0.27
Yes	1.14 (0.78, 1.67)		0.60 (0.29, 1.24)		1.43 (0.76, 2.68)	
Dark green leafy vegetables						
No	Reference	0.71	Reference	0.92	Reference	0.45
Yes	1.05 (0.0, 1.39)		1.02 (0.65, 1.62)		0.87 (0.61, 1.25)	
Other vegetables						
No	Reference	0.97	Reference	0.69	Reference	0.20
Yes	1.01 (0.74, 1.37)		0.89 (0.51, 1.56)		0.79 (0.55, 1.14)	
Fruits						
No	Reference	0.86	Reference	0.71	Reference	0.55
Yes	0.96 (0.62, 1.49)		0.84 (0.34, 2.09)		1.15 (0.73, 1.79)	
Dairy						
No	Reference	0.32	Reference	**0.05****	Reference	**<.01****
Yes	1.12 (0.90, 1.40)		0.71 (0.50, 0.99)		1.53 (1.17, 2.00)	
Eggs						
No	Reference	**0.06***	Reference	**0.04****	Reference	0.39
Yes	0.63 (0.38, 1.03)		0.36 (0.13, 0.98)		1.35 (0.69, 2.64)	
Meat, poultry and fish						
No	Reference	**<.01****	Reference	**<.01****	Reference	0.28
Yes	0.00 (0.00, 0.00)		0.00 (0.00, 0.00)		4.30 (0.31, 59.21)	
Junk foods (≥3x/week)						
No	Reference	**0.09***	Reference	0.65	Reference	0.52
Yes	0.67 (0.43, 1.05)		0.86 (0.44, 1.66)		0.81 (0.42, 1.55)	

Variables	Total		Male		Female	
	OR (95% CI)	**p**	**OR (95% CI)**	**p**	**OR (95% CI)**	**p**
Fried foods (≥3x/week)						
No	Reference	0.40	Reference	0.27	Reference	**0.07***
Yes	0.88 (0.67, 1.17)		0.78 (0.49, 1.22)		1.41 (0.97, 2.05)	
Sweets (≥3x/week)						
No	Reference	0.86	Reference	0.99	Reference	**0.07***
Yes	1.04 (0.66, 1.64)		1.00 (0.39, 2.58)		1.65 (0.96, 2.83)	
Aerated drinks (≥3x/week)						
No	Reference	**<.01****	Reference	**0.04****	Reference	0.56
Yes	0.49 (0.31, 0.77)		0.55 (0.31, 0.97)		1.24 (0.60, 2.58)	
Minimum dietary diversity						
No	Reference	0.23	Reference	**0.04****	Reference	0.65
Yes	0.80 (0.56, 1.15)		0.45 (0.21, 0.95)		0.90 (0.56, 1.43)	

Logistic regression was used to estimate OR and 95% CI for anemia status

* p-value < 0.20

** p-value < 0.05

[a] Not available because *n* is too small

Table 4. Univariate correlates of Hb concentrations of adolescents aged 15-19 years in the CNNS data

Variables	Total		Male		Female	
	β (95% CI)	**p**	**β (95% CI)**	**p**	**β (95% CI)**	**p**
Sociodemographic						
Schooling status						
Not in school	Reference	**0.14***	Reference	0.75	Reference	0.59
Currently in school	0.30 (-0.10, 0.71)		-0.08 (-0.61, 0.44)		0.12 (-0.32, 0.57)	
Mother education						
≤8 years	Reference	**0.02****	Reference	0.46	Reference	**0.17***
>8 years	0.27 (0.04, 0.50)		0.09 (-0.15, 0.34)		0.15 (-0.06, 0.35)	
Religion						
Hindu	Reference	0.99	Reference	0.18	Reference	0.97
Others	-0.00 (-0.28, 0.27)		0.17 (-0.14, 0.48)		0.01 (-0.26, 0.27)	
Caste/Tribe						
Scheduled caste	-0.23 (-0.50, 0.03)	**<.01****	-0.19 (-0.46, -0.08)	**<.01****	-0.28 (-0.58, 0.02)	**<.01****
Scheduled tribe	-0.55 (-0.83, -0.27)		-0.72 (-1.01, -0.42)		-0.59 (-0.91, -0.26)	
Other backward class	0.03 (-0.19, 0.25)		0.08 (-0.15, 0.30)		-0.16 (-0.37, 0.04)	
Non-backward class	Reference		Reference		Reference	
Residence						
Rural	Reference	0.28	Reference	0.21	Reference	0.80
Urban	0.11 (-0.09, 0.31)		0.11 (-0.06, 0.29)		0.03 (-0.20, 0.26)	
Wealth index						
Lowest	-0.17 (-0.46, 0.12)	**<.01****	-0.25 (-0.62, 0.12)	**<.01****	0.07 (-0.23, 0.37)	0.82
Low	0.10 (-0.18, 0.38)		0.01 (-0.29, 0.31)		0.06 (-0.26, 0.37)	
Middle	Reference		Reference		Reference	
High	0.09 (-0.18, 0.37)		0.20 (-0.05, 0.45)		0.04 (-0.25, 0.34)	
Highest	0.34 (0.10, 0.58)		0.32 (0.09, 0.54)		0.17 (-0.11, 0.46)	
IFA supplements						
No/do not know	Reference	**<.01****	Reference	**0.07***	Reference	0.64
Yes	-0.47 (-0.79, -0.15)		-0.29 (-0.61, 0.03)		-0.10 (-0.52, 0.32)	
Deworming tablet						
No/do not know	Reference	**0.02****	Reference	**<.01****	Reference	**0.13***
Yes	-0.21 (-0.38, -0.04)		-0.28 (-0.46, -0.09)		0.18 (-0.05, 0.41)	
Anthropometric status						
HAZ						
<-2SD	-0.19 (-0.37, -0.00)	**0.05****	-0.11 (-0.31, 0.08)	0.25	-0.11 (-0.32, 0.10)	0.32
Normal	Reference		Reference		Reference	
BMIZ						
<-2SD	0.29 (0.11, 0.48)	**<.01****	-0.25 (-0.44, -0.05)	**0.01****	0.15 (-0.07, 0.38)	0.36
Normal	Reference		Reference		Reference	
>+2SD	0.59 (-0.09, 1.26)		0.31 (-0.14, 0.76)		0.16 (-0.30, 0.62)	
MUACZ						
<-2SD	0.19 (0.02, 0.37)	**0.03****	-0.50 (-0.68, -0.32)	**<.01****	-0.08 (-0.30, 0.15)	0.51
Normal	Reference		Reference		Reference	

Variables	Total		Male		Female	
	β (95% CI)	**p**	**β (95% CI)**	**p**	**β (95% CI)**	**p**
TSFTZ						
<-2SD	-0.71 (-1.06, -0.36)		-0.20 (-0.66, 0.26)		0.05 (-0.32, 0.42)	
Normal	Reference	**<.01****	Reference	0.14	Reference	0.80
>+2SD	N/A[a]		N/A[a]		N/A[a]	
SSFTZ						
<-2SD	-0.01 (-0.51, 0.49)		-0.47 (-1.00, 0.06)		0.43 (-0.39, 1.26)	
Normal	Reference	0.96	Reference	**0.09***	Reference	0.30
>+2SD	N/A[a]		N/A[a]		N/A[a]	
WCZ						
<-2SD	-0.24 (-0.44, -0.04)		-0.47 (-0.72, -0.23)		0.10 (-0.13, 0.33)	
Normal	Reference	**0.01****	Reference	**<.01****	Reference	0.40
>+2SD	N/A[a]		N/A[a]		N/A[a]	
Dietary						
Starchy staples						
No	Reference	**<.01****	Reference	0.36	Reference	0.86
Yes	-0.30 (-0.51, -0.09)		-0.10 (-0.32, 0.12)		0.02 (-0.19, 0.23)	
Pulses: beans, peas, lentils						
No	Reference	0.74	Reference	0.89	Reference	**0.05****
Yes	-0.03 (-0.22, 0.15)		-0.02 (-0.24, 0.21)		0.21 (0.00, 0.41)	
Nuts and seeds						
No	Reference	0.82	Reference	**0.08***	Reference	0.83
Yes	0.03 (-0.26, 0.33)		0.35 (-0.04, 0.73)		-0.05 (-0.52, 0.41)	
Dark green leafy vegetables						
No	Reference	0.21	Reference	0.75	Reference	0.35
Yes	-0.15 (-0.38, 0.08)		0.05 (-0.23, 0.32)		0.11 (-0.12, 0.34)	
Other vegetables						
No	Reference	**0.03****	Reference	0.95	Reference	**0.13***
Yes	-0.23 (-0.45, -0.02)		0.01 (-0.24, 0.26)		0.18 (-0.05, 0.40)	
Fruits						
No	Reference	0.54	Reference	0.93	Reference	0.93
Yes	0.10 (-0.23, 0.44)		0.01 (-00.27, 0.29)		0.01 (-0.28, 0.31)	
Dairy						
No	Reference	0.82	Reference	**0.13***	Reference	**0.02****
Yes	-0.02 (-0.22, 0.18)		0.14 (-0.04, 0.33)		-0.22 (-0.41, -0.03)	
Eggs						
No	Reference	**<.01****	Reference	0.06*	Reference	0.70
Yes	0.67 (0.20, 1.14)		0.37 (-0.01, 0.75)		0.14 (-0.56, 0.84)	
Meat, poultry and fish						
No	Reference	**<.01****	Reference	**<.01****	Reference	0.20
Yes	0.64 (0.37, 0.91)		-0.52 (-0.79, -0.25)		-0.29 (-0.72, 0.15)	
Junk foods (≥3x/week)						
No	Reference	**<.01****	Reference	0.73	Reference	**0.13***
Yes	0.52 (0.22, 0.84)		0.06 (-0.29, 0.41)		0.28 (-0.08, 0.64)	

Variables	Total		Male		Female	
	β (95% CI)	**p**	**β (95% CI)**	**p**	**β (95% CI)**	**p**
Fried foods (≥3x/week)						
No	Reference	**0.04****	Reference	0.10*	Reference	**0.02****
Yes	0.28 (0.01, 0.56)		0.19 (-0.04, 0.42)		-0.36 (-0.67, -0.05)	
Sweets (≥3x/week)						
No	Reference	**0.14***	Reference	0.89	Reference	0.58
Yes	0.27 (-0.09, 0.63)		0.03 (-0.36, 0.42)		-0.14 (-0.63, 0.35)	
Aerated drinks (≥3x/week)						
No	Reference	**<.01****	Reference	0.15*	Reference	0.72
Yes	0.86 (0.53, 1.19)		0.20 (-0.07, 0.46)		-0.10 (-0.63, 0.43)	
Minimum dietary diversity						
No	Reference	0.28	Reference	0.54	Reference	**0.03****
Yes	0.14 (-0.12, 0.40)		0.07 (-0.17, 0.32)		0.37 (0.05, 0.70)	

Linear regression was used to measure change in β and 95% CI for Hb concentrations

* p-value < 0.20

** p-value < 0.05

Minimum Dietary Diversity and Anemia and Hb Concentrations

Table 5 presents the comparison between unadjusted and adjusted analyses of meeting MDD on anemia and Hb concentrations. In unadjusted analysis, there was a significant association between meeting MDD and lower odds of anemia in male adolescents (OR: 0.45, 95% CI: 0.27, 0.95) and between meeting MDD and higher Hb concentrations in female adolescents (β: 0.37, 95% CI: 0.05, 0.70). No significant association was found between meeting MDD and odds of anemia in the total and females, as well as between meeting MDD and Hb concentrations in the total and males ($p>0.05$). In the final models, the association between meeting MDD and higher Hb concentrations persisted in female adolescents (β: 0.34, 95% CI: 0.01, 0.66) after adjusting for confounders with $p<0.20$ from univariate analysis. In contrast, the association between meeting MDD and lower odds of anemia in unadjusted analysis for male adolescents were no longer significant (OR: 0.49, 95% CI: 0.23, 1.05) after adjusting for confounders with $p<0.20$ from univariate analysis.

Table 5. Unadjusted vs. adjusted analyses of the MDD on anemia and Hb concentrations of adolescents aged 15-19 years in the CNNS data

Variables	Unadjusted		Adjusted[†]	
	OR or β (95% CI)	**p**	**OR or β (95% CI)**	**p**
MDD and anemia (logistic regression)				
Total	0.80 (0.56, 1.15)	0.23	0.83 (0.59, 1.20)[a]	0.33
Male	0.45 (0.27, 0.95)	**0.04****	0.50 (0.24, 1.05)[b]	0.07
Female	0.90 (0.56, 1.43)	0.65	0.88 (0.55, 1.40)[c]	0.58
MDD and Hb concentrations (linear regression)				
Total	0.14 (-0.12, 0.40)	0.28	0.08 (-0.18, 0.34)[d]	0.55
Male	0.07 (-0.17, 0.32)	0.54	-0.01 (-0.26, 0.25)[e]	0.96
Female	0.37 (0.05, 0.70)	**0.03****	0.34 (0.01, 0.66)[f]	**0.04****

** p-value < 0.05

[†] We considered known or suspected risk factors for anemia as potential confounders. These potential confounders were included if p<0.20 from univariate regression models assessing association with MDD of each variable (linear or binomial regression model beta coefficients; likelihood ratio tests). Based on a change in estimate approach, covariates were included in the final adjusted model if they changed the estimate by ≥10%. The final covariates for the association of the MDD on anemia and Hb concentrations were utilized in final models in this Table.

[a] Adjusted for wealth index

[b] Adjusted for wealth index

[c] Adjusted for sweets (≥3x/week)

[d] Adjusted for mother education, wealth index, IFA supplements, HAZ, WC z-score, and fried foods (≥3x/week)

[e] Adjusted for caste/tribe, wealth index, IFA supplements, BMI z-score, MUAC z-score, SSFT z-score, WC z-score, and fried foods (≥3x/week)

[f] Adjusted for caste/tribe

DISCUSSION

Population Characteristics

This cross-sectional analysis aimed to (1) determine the prevalence and correlates of anemia, and (2) examine whether MDD is associated with anemia among adolescents aged 15-19 years in India who participated in the CNNS. One-third of adolescents in this population was anemic. This prevalence was higher than the global prevalence of anemia in adolescents (24%) reported in 2016 (11). The current study also found that the prevalence of anemia was higher in females (47.5%) compared to males (18.3%), which was consistent with results from the National Family Health Survey-5 (NFHS-5) India 2019-2021 (38).

The current study revealed a higher proportion of stunted adolescents in the anemic group compared to the non-anemic group, which is consistent with previous studies (39–42). While previous studies have primarily focused on children under five years old, this study highlights that a higher proportion of stunting is observed in the anemic population among adolescents. These findings suggest that a possible co-occurrence of stunting and anemia might be prevalent not only in young children, but also in adolescents.

Among adolescents aged 15-19 years with available dietary data, the prevalence of meeting MDD was found to be less than 10%, which is substantially lower than the prevalence reported in other studies. For instance, in a 2019 study among rural land-holding households in eight sub-Saharan African countries, the prevalence of meeting MDD (≥5 food groups) ranged from 47% to 79% depending on the agricultural season (43). Similarly, among WRA in the Kalalé district of northern Benin and villages of Southwest Cameroon, the prevalence of meeting MDD was found to be 45% and 61%, respectively (44,45). In Ethiopia, a study found that 51% of the population consumed four or more food groups based on a diet diversity score (46).

One possible explanation for the lower levels of MDD observed in this study compared to validated methods may be due to differences in the methodology used to assess dietary diversity. Validated methods relied on quantitative 24-hour dietary recall, while the CNNS dataset in this study used daily and seven-day FFQs. The 24-hour dietary recall approach only captures what an individual consumed in the 24 hours prior to the interview, which may not be a representative sample of their typical dietary patterns. In contrast, the utilization of FFQs in this study enabled stricter inclusion criteria for meeting MDD, where adolescents were only included if they consumed at least four food groups for seven days per week consecutively. This more rigorous criterion may have contributed to the lower percentage of individuals who met the MDD criterion in this study.

Correlates of Anemia and Hb Concentrations

The results of this study revealed that caste/tribe was strongly associated with the odds of anemia and Hb concentrations. Specifically, individuals from scheduled tribe had a higher likelihood of anemia and lower Hb concentrations across both sex and the entire population. This finding was consistent with a study done by Vart et al (47) showing significant association between caste and childhood anemia in India. One possible explanation for these findings is that individuals from these caste/tribe typically come from a low socio-economic background and may face challenges, such as poor living and working conditions, unhealthy behaviors, limited access to healthcare, and noncompliance with iron supplements (47). Furthermore, the association between wealth index (highest) and lower odds of anemia prevalence and higher Hb concentrations in males might support this explanation.

The consumption of IFA supplements did not demonstrate a significant association with the likelihood of lower anemia prevalence and higher Hb concentrations in either males or females. Conversely, it was observed that the consumption of IFA supplements was significantly associated with the odds of anemia and lower Hb concentrations in the total population analysis. There are several potential reasons for this finding. Firstly, the accuracy of assessing compliance and adherence to IFA supplement consumption was limited as the study solely relied on self-reported questionnaire data. Additionally, the analysis did not take into account the presence of infection or inflammation, which could have impaired iron absorption (23,34,48).

In terms of anthropometric status, a higher proportion of males were malnourished than females, as demonstrated by lower scores for BMIZ, MUACZ, and WCZ. Further analysis revealed that these malnutrition parameters were associated with higher anemia prevalence and lower Hb concentrations in males. Despite the higher prevalence of malnutrition in males, the prevalence of anemia was higher in females than in males. The results underscore the importance of addressing malnutrition in male adolescents, and investigating other sex-specific risk factors for anemia to develop targeted interventions to prevent and treat anemia.

The current study indicates that daily consumption of starchy staples was significantly associated with higher odds of anemia and lower odds of Hb concentrations in the total population. This observation may be explained by the presence of phytates in starchy staples, which are known to inhibit the absorption of iron (49,50). Additionally, the study revealed a low proportion of heme iron from animal protein and IFA supplements consumption, which could worsen the iron bioavailability.

Daily consumption of meat, fish, and poultry were significantly associated with lower odds of anemia in the total population and males but not females. Animal protein, particularly red meat, is vital source of heme iron that is more easily absorbed by the body than non-heme iron present in plant-based foods (51). The linear regression model found the positive association between daily consumption of meat, fish, and poultry with higher Hb concentrations, but this association was reversed in males. This inconsistent finding could be attributed to the occurrence of Simpson's Paradox, a phenomenon that can lead to contradictory results between overall and subgroup analyses of the same data (52–54).

Interestingly, the study found that daily consumption of dairy in females was associated with higher odds of anemia and lower Hb concentrations. This may be due to the high levels of calcium found in dairy products, which can inhibit iron absorption in the absence of sufficient iron-rich foods in the diet (55). However, a systematic review and meta-analysis examining the relationship between cow's milk consumption and anemia in children noted several methodological flaws that limit the evidence (56). Consequently, additional research and validation are needed to determine the association between dairy consumption and anemia and lower Hb concentrations in female adolescents.

In addition, the consumption of other beverage types, such as aerated drinks at least three times a week, was linked to lower odds of anemia and higher Hb concentrations. This finding contradicts the idea that carbonated beverages impede iron absorption (57). As a result, the reason behind this finding remains unclear. Another reason for the unclear finding could be the nature of a cross-sectional design, which limits the ability to establish a causal relationship between carbonated beverage consumption and anemia. Further research using longitudinal or interventional study designs may help to clarify this association.

Minimum Dietary Diversity and Anemia and Hb Concentrations

The present study showed that meeting MDD, defined as consuming at least four food groups per day was associated with a lower likelihood of anemia in male adolescents and higher Hb concentrations in female adolescents. However, the findings also suggest that dietary diversity may not be the only determining factor for anemia in male adolescents, as the association was not observed in adjusted analysis. The identification of numerous other factors associated with anemia and Hb concentrations in males, but not in females, in this analysis, highlights the need for further research to understand the complex interplay of various factors contributing to anemia and Hb concentrations in different population groups.

In females, the association between meeting MDD and higher Hb concentrations persisted in adjusted analysis. These results are consistent with other investigations (22,27,28,33,58). It is worth noting that the dietary diversity questionnaire has been validated mostly in children under 5 years (59) and women of reproductive age (60), but not in men. Therefore, the lack of association in males may be due to limitations of the questionnaire in capturing the diversity of their diets. Nonetheless, the current findings highlight the importance of promoting a diverse and balanced diet, especially among female adolescents, as a potential strategy to improve Hb concentrations and prevent anemia.

This study is subject to several limitations. First, the CNNS data used in this study was cross-sectional, which limits the ability to establish causal relationships between meeting MDD and anemia or Hb concentrations. Second, the study relied on self-reported dietary information, which may be subject to recall bias. Additionally, as the dietary data were collected using a non quantitative FFQs, the quantity of each food group consumed was not measured, making it difficult to determine the amount of nutrients, including iron, obtained from the diet. This information would have been useful in understanding the association between dietary diversity and anemia in this population. Furthermore, other information such as physical activity, caffeinated drinks consumption, smoking behavior, menstrual cycle, and infection such as tuberculosis could also be examined to better understand the factors associated with disparity in anemia prevalence between male and female adolescents. Future studies could also investigate the longitudinal association between meeting MDD and anemia and Hb concentrations while also addressing these limitations.

CONCLUSION

The present study provides insights into anemia and Hb concentrations and their association with MDD among adolescents aged 15-19 years in India. The results emphasize the significance of addressing various factors, including sociodemographic aspects such as caste/tribe, anthropometric status such as BMIZ, MUACZ, and WCZ, and dietary factors such as starchy staples and animal source foods, in efforts to combat anemia and improve Hb concentrations. The MDD was associated with lower odds of anemia in males in unadjusted analysis, while in females MDD was associated with higher Hb concentrations in unadjusted analysis and after adjusting for caste/tribe variable.

Sex-specific interventions may be required to address the dietary risk factors for anemia and lower Hb concentrations. Promoting a diverse diet may help improve Hb concentrations among some adolescents. Nonetheless, while designing interventions to combat anemia among male adolescents, other contributing factors such as anthropometric status should also be considered. These findings highlight the need for comprehensive, tailored interventions to address the complex, multifaceted factors associated with anemia and lower Hb concentrations among adolescents in India.

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