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Understanding the determinants of hemoglobin and iron status: adolescent–adult women comparisons in SANHANES-1

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The study compared hemoglobin (Hb) and serum ferritin levels between adolescent and adult women with different body mass indices, dietary intake, and sociodemography. A secondary analysis of data for 3177 South African women ≥15 years of age who participated in the SANHANES-1 study was undertaken. Abnormal Hb (≤12 g/dL) and serum ferritin (<15 μg/mL) were based on the World Health Organization's criteria for nonpregnant women aged ≥15 years. Data were analyzed using STATA version 11. Overall, anemia was detected in 740 (23.3%) participants. Of the individuals in the subsample (*n* = 1123, 15–35 years) who had serum ferritin measured, 6.0% presented with iron depletion (ID) and 10.8% presented with iron-deficiency anemia (IDA). The highest prevalences of anemia, ID, and IDA were in 15- to 18-year-olds (11.2%, 8.8%, and 20.2%, respectively). Black young adults (19–24 years) were up to 40 times more likely to present with ID compared with their non-black counterparts. While overweight adolescents were three times more likely to be anemic, overweight and obese young adults, as well as obese older adults (25–35 years), were less likely to be anemic compared with normal-weight women of all age groups. Overconsumption of dietary fat increased ID by up to 54- and 11-fold (adolescents and 25- to 35-year-olds, respectively). In South Africa, anemia is most prevalent in adolescents and black women. Anemia is also an indicator of overconsumption of dietary fat and a marker of socioeconomic disadvantage.

Keywords: anemia; iron depletion; iron-deficiency anemia; SANHANES-1; adolescents; young adults

Background

Iron deficiency is one of the most common micronutrient deficiencies globally and is mostly prevalent in disadvantaged communities, especially in Africa.[1–3] Iron deficiency often manifests as serum iron depletion (ID) or an abnormally low level of red blood cells as a result of insufficient mineral iron in the body. Mineral iron is mainly obtained by consuming foods, such as cooked green leafy vegetables, meat and organ meat, cooked lentils, and fortified cereals, which contain high levels of easily accessible and available iron. Iron stores/red blood cells can also be diminished during menstruation, during bouts of infections, and as a result of chronic non-communicable diseases (NCDs).[4] Hence, the research done in Africa has shown that this condition is more prevalent/common among women of reproductive age, people who have limited access to basic needs (such as sanitation and treated water), and people exposed to infectious diseases and those at risk of NCDs.[5–11]

Until recently, there has been a dearth of up-to-date data regarding the existence and manifestation of iron deficiency in a nationally representative sample of South African women of reproductive age. The only available data were collected in 2000 (the South African Comparative Risk Assessment (SA CRA))[12] and in 2005 (the National Food Consumption Survey Fortification Baseline

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(NFCS-FB-I)).[13] The study in 2000[12] was a data-modeling study based on the first South African National Burden of Disease study, conducted in the year 2000, to identify the underlying causes of premature mortality and morbidity experienced in South Africa (SA); the latter study[13] was a cross-sectional survey of a nationally representative sample of women of reproductive age (16–35 years) living in the same households with their 1- to 9-year-old children. In both of these studies, it was found that almost one-third of women and children in SA were anemic on the basis of hemoglobin (Hb) concentrations. Moreover, one out of five women had poor iron status. These studies and other localized studies[5,14] showed that the suboptimal diets, the gradual but substantial increase in fruit intake, and the increased intake of animal foods that were characteristic of "Western diets" (diets typically high in sugar and fat) could be attributed to poverty and social inequality that predisposed these South Africans to micronutrient deficiencies. Although these studies acknowledged that the burden due to iron-deficiency anemia (IDA) in SA appeared to be lower than that of women in other developing countries, they recommended the promotion of food-based dietary guidelines as well as monitoring of the food-fortification programs that promoted the consumption of iron-rich foods in SA.

On the basis of the aforementioned recommendations, the South African Department of Health has since introduced the Integrated Nutrition Programme, a comprehensive nutrition strategy that includes iron supplementation targeting children under 6 years of age, at-risk pregnant and lactating women, and those affected by communicable diseases.[15] The main challenge associated with the aforementioned iron supplementation is that it is designed to take place at a primary healthcare level and hence it is only accessible to populations that access health facilities. As such, it does not cater to the entire vulnerable South African population, especially nonpregnant women of reproductive age, school-aged children, and the elderly. Other interventions that have shown promise in reducing nutrient deficiencies in SA are the Food Fortification Programme (FFP),[16] a compulsory government initiative that mandates that millers fortify staple foods (such as maize meal and flour) with essential nutrients, including iron, as well as the National School Nutrition Programme (NSNP),[17] a state-funded nutritional program that delivers cooked breakfast or lunch consisting of a starch, a protein, and a vegetable, to all quintile 1–3 primary schools nationally. While the FFP services the entire population, the NSNP services children in the most deprived communities in SA. Recent evaluation studies[18–20] have suggested modest positive findings with regard to malnutrition secondary to the aforementioned programs. Hence, these studies suggested a need for an operational surveillance system to monitor the program coverage. Moreover, some recommendations have been made suggesting the extension of these programs to other vulnerable populations, including nonpregnant women of reproductive age, especially "deprived" young adults (15–19 years).[15]

Recent localized studies in SA also increased awareness of other important factors that fuel anemia in the country.[7–9] These factors include inflammation due to infectious diseases (tuberculosis (TB) and HIV/AIDS), chronic diseases (especially chronic kidney failure), and selected drug therapies.[7–9] These studies showed that, in SA, anemia appeared to be more prevalent in certain segments of the population (i.e., black ethnic groups, communities that grapple with poverty, and those that have limited access to basic and health services), as well as in people who are overweight or obese.[10,21]

The South African National Health and Nutrition Examination Survey (SANHANES-1)[22] was introduced in 2012 to act as the suggested surveillance survey to assess the health and nutritional status (i.e., the anthropometry and nutrient deficiencies) of South Africans across their life span with respect to the prevalence of NCDs (specifically focusing on cardiovascular disease, diabetes, and hypertension) and their risk factors (food security, diet, physical activity, alcohol and tobacco use, stress disorders, as well as access to health services). The current research then builds on the data obtained from SANHANES-1 and further explores the extent of Hb and iron status of South African women of childbearing age (15–35 years). Particular emphasis has been placed on the specific sociodemographic and dietary-related determinants of anemia and iron status in different age groups of these women. Moreover, the association between the Hb, iron, and body mass index (BMI) status of these women was explored. The outcomes of this research may also contribute to the design of targeted intervention programs for the prevention and treatment of micronutrient deficiencies (anemia in particular) in South African women.

Methods

Study design and study population

The current study is based on secondary analysis of data from 3177 South African women aged 15 years and older who participated in SANHANES-1.[22] The SANHANES-1 was a cross-sectional household survey conducted in 2012 that obtained data through interviews, clinical examination, and collection of blood samples. Individuals of all ages living in occupied households were eligible to participate in the survey. Individuals were excluded if they lived in educational institutions, old-age homes, hospitals, or uniformed service barracks or were homeless. In this analysis, only the women's data were used, and these were weighted to represent the South African age, ethnic diversity, and geographic location (with reference to rural and urban settings) distribution on the basis of the 2011 Census.[23]

Biomarker measurements

The current analyses therefore included 3177 nonpregnant women $\geq$15+ years of age with valid data on Hb levels. Blood specimens were collected by registered and trained nurses and/or doctors from consenting volunteers at healthcare centers in all provinces across SA. The collected blood samples were aliquoted into the appropriate blood specimen collection tubes, mixed as necessary, and stored in cooler boxes (containing ice packs), which were couriered daily to reach the laboratories for analysis within 24 h of blood sample collection. The South African National Accreditation System (SANAS)-accredited laboratories Pathcare and Lancet analyzed the blood specimens on the basis of the laboratory branches that were available in each South African province. Automated techniques, including Roche Modular, Immulite 2000, BioRad D10, and Abbot Architect and high-performance liquid chromatography (HPLC), were used for each biomarker (glycated hemoglobin (HbA1c), C-reactive protein (CRP), Hb, and ferritin levels) analysis. Deviations from the established internal and external quality control procedures had to be reported per contractual agreement; however, no deviations were reported. Analytical quality control documentation, which was standard procedure in the two accredited laboratories, indicated that the coefficient of variation for the analyses ranged from 0.5% to 3.75%.

Measurements for anemia

The red blood cell count was undertaken to determine Hb and serum ferritin levels. Abnormal Hb (presence of all causes of anemia (i.e., anemia due to a concoction of factors that include loss of blood, malnutrition, inflammation caused by chronic diseases, and/or infection with viruses and nematodes)) was based on World Health Organization (WHO) criteria,[24] namely, Hb $\leq$ 12 g/dL for nonpregnant women $\geq$15 years of age.[24] Anemia levels were further broken down to different levels of severity (i.e., mild (Hb: 11–11.9 g/dL), moderate (Hb: 8–10.9 g/dL), and severe (Hb $<$ 8 g/dL) anemia).[24] A close analysis of households that had one or more cases of anemia was undertaken. In this case, 440 households were included in this analysis. A further close analysis of 1123 participants (15–35 years) with valid data on other indicators of serum iron concentration (in the form of the amount of ferric iron [Fe^{3+}] (i.e., the level of serum ferritin)) was undertaken. In this case, normal and low serum ferritin were shown as ferritin levels $\geq$15 or $<$15 μg/mL, respectively, also based on WHO criteria.[22]

Anthropometric variables

Body weight, height, and BMI of the 3177 participants were measured and calculated using the techniques described by Lee and Nieman[25] and indicated as percentiles[26] for adolescents (15- to 18-year-olds) and as kg/m^2 for adults ($\geq$19 years). Underweight was equal to BMI below the fifth percentile for children and BMI $<$ 18.5 kg/m^2 for adults. Normal weight was defined as BMI between the 5th and 84.9th percentile for children and BMI between 18.5 and 24.9 kg/m^2 for adults. Overweight was defined as BMI between the 85th and 94.9th percentile for adolescents and BMI between 25 and 29.9 kg/m^2 for adults. Obesity was defined as BMI $\geq$ the 95th percentile (adolescents) and BMI $\geq$ 30 kg/m^2 (adults).

The questionnaire

A previously validated questionnaire for use in South African communities examining information on sociodemographic characteristics, namely, age, ethnicity, gender, socioeconomic status (defined on the basis of the household income), marital status, and education level, was administered to the participants. In addition, the questionnaire assessed dietary intake of participants on the basis of a list of food groups they consumed and the frequency of consuming these food items each day. The food assessed included green leafy vegetables, as well as food high in sugar/fat. The sugar score was calculated using the number and frequency of sugary foods (such as sweetened beverages, confectionaries, and sweet snacks) consumed by the participants each day. The scores ranged from 0 to 8. High, moderate, and low scores were regarded as 6–8, 3–5, and 0–2 food items, respectively. The fat score was calculated using the number and frequency of fatty foods (such as processed meat, fried foods, and high-fat snacks) consumed by the participants each day. High, moderate, and low scores were regarded as 15–20, 8–14, and 0–7 food items, respectively. Participants were also probed regarding whether they ate any form of meat, including white or red meat with visible fat. Finally, household food security was measured using the Community Childhood Hunger Identification Project (CCHIP) index.[27] The CCHIP index consists of eight questions that assess the existence of hunger and the level and severity of food security (food access) within households. A score of 1–4 affirmative responses obtained using the CHHIP index indicates that a household is "at risk of hunger" owing to at least one sign of a food shortage problem. A score of five or more affirmative responses indicates a food shortage problem affecting everyone in the household. This score also indicated more than five different signs of hunger where at least one of these signs directly affects children in the household.

Other measurements

The investigation of NCDs and communicable diseases (e.g., HIV/AIDS and TB) was outside the scope of the current research. However, we undertook simple associations between anemia, ID, and IDA prevalence and blood pressure (BP), HbA1c, and CRP, the latter being a marker for inflammation[28] prevalence. BP was measured using an Omron Automatic Digital BP Monitor (model M2, Omron Healthcare, Bannockburn, IL). Normal (systolic BP (SBP) $<$ 120 mmHg and diastolic BP (DBP) $<$ 80 mmHg), prehypertension (SBP 120–139 mmHg; DBP 80–89 mmHg), and high BP or hypertension (SBP $\geq$ 140 mmHg; DBP $\geq$ 90 mmHg) were measured on the basis of the U.S. Department of Health and Human Services[29] criteria. HbA1c, on the other hand, is a gold standard test endorsed by the WHO[30] to monitor long-term blood sugar control in participants. The WHO cutoff value used was HbA1c $\geq$ 6.1% to show uncontrolled/abnormal values in addition to screening for blood glucose levels. The HbA1c was measured using HPLC. Finally, CRP, a marker of inflammation, was measured by determining serum CRP. The presence of inflammation was determined as being low if the serum CRP level was less than 1.0 mg/L, moderate if the serum CRP level was between 1.0 and 3.0 mg/L, and high if the serum CRP was above 3.0 mg/L.[31]

Statistical analysis

The analysis was undertaken using STATA version 11.0 (StataCorp, 2009) and Microsoft Excel. All data entered were checked for errors and cleaned before undertaking the analysis. The "svy" method in STATA was used to produce estimates that adjust for the complex, multilevel sampling design. In the current analyses, the survey sample was stratified by province and enumerator areas. In this regard, "svy" was used to account for unequal sampling probabilities in order to benchmark (standardize) the sample to represent the South African Census 2011 population estimates.[23] Weighted data were analyzed using univariate, bivariate, and multilevel analysis techniques. Estimates (means and prevalence rates) were reported with their corresponding 95% confidence intervals (CI) and standard errors of means. Any differences in CI values were considered to be significant if they did not overlap and their *P* values were $<$0.05. Moreover, relative risk and odds ratio estimates were presented with CI, and the *P* values were used to confirm significant differences.

Ethical issues

SANHANES-1 received ethics approval from the Research Ethics Committee of the Human Science Research Council (HSRC) of SA (REF: REC6/16/11/11). Participation in the study was voluntary, and all survey participants signed informed consent forms that had been explained to them. All data and blood specimens collected from the participants were anonymized. Study identity numbers were used as identifiers of the data and specimens, with all personal information kept separate from the data. Only one primary investigator and the HSRC's chief statistician had access to these details. Permission for using the anonymized SANHANES-1 data was obtained from the principal investigator of SANHANES-1, and a nondisclosure agreement had to be signed.

Results

Characteristics of all the participants

Sociodemography. Table 1 shows complete data for 3177 participants ≥15 years of age. While there was almost an equal spread in age and income quantile[a] groups of the participants, the majority were black South Africans (83.6%) (a typical situation in the South African population, as shown by the Census data[23]) living in the urban formal areas (49.3%) (data not shown), never married (60.2%), and who had completed their secondary education (grades 8–12) (61.2%).

Body mass index. Table 1 also shows that 3.3%, 31.5%, 26.3%, and 38.9% of the participants were underweight, normal weight, overweight, and obese, respectively.

Food access and dietary behavior. It was also observed that 32.5%, 77.0%, 68.1%, and 41.7% of the participants experienced hunger, consumed green leafy vegetables fewer than four times a week, ate red meat with visible fat, and had higher fat scores, respectively (data not shown) .

Hemoglobin status of all participants. Overall, age-standardized anemia was detected in 740 (23.3%) of the 3177 participants (Table 1). While there were no significant differences in the anemia prevalence within the marital status and income quantile groups, the highest prevalence of detected anemia (32.5%) was observed in adolescents. This prevalence was significantly different from that of the young adults (19–24 years) and ≥55-year-old participants. In addition, the highest prevalence of detected anemia was observed in the Indian group (31.7%), and this prevalence was significantly different from that of their white and colored counterparts. Moreover, black participants had a prevalence of 25.4%, which was significantly higher than that of the white and colored groups. Finally, the lowest prevalence of anemia was observed in participants who completed matriculation (11.4%). This prevalence was significantly lower than that of the participants who had no formal schooling or those who managed to complete only grade 7, as well as those who completed their secondary education.

Cases of anemia in South African households

Of the total households in the sample of 3177, 440 had valid data on Hb. Of these 440 households, 183 (41.6%) households had at least one case of anemia. Within these 183 households, 17.2%, 20.5%, and 9.2% had at least one adolescent, one adult, or one adolescent–adult pair with anemia, respectively. The prevalence of anemia did not differ by age, gender, level of education, or income of the household head. However, the prevalence of an anemic adolescent–adult pair within the same household was significantly higher in households belonging to the lower income quantile (10.4% ($n = 14$, 95% CI: 5.7–24.2)) compared with in the upper income quantile (1.1% ($n = 1$, 95% CI: 0.2–5.2)) (data not shown).

On the basis of the multivariate, multinomial logistic regression model (Table 2), the household factors (i.e., age, race, education level, locality, and food security) had a significant influence on anemia status within the 440 households (Probit: $F = 0.0354$). A close analysis of these household factors showed that households with household heads who were black South Africans and had completed matriculation (grade 12) and/or possibly completed tertiary education were 22.0 and 4.3 times more likely to have at least one case of an adolescent–adult pair that was anemic compared with households with household heads who were non-black or had education level less than grade 8 and were not working. Those households that belonged to the upper income quantile, on the other hand, were less likely (RRR: 0.75, $P = 0.025$) to have cases of adolescent–adult pairs that were anemic.

Comparing hemoglobin and iron status in the subpopulation of women of reproductive age (15–35 years)

Hemoglobin and iron status. The analysis of data of the 1123 participants who had valid data on ferritin (Table 3) showed that, overall, 6.0%, 10.8%, and 12.5% (age-standardized data) presented with ID, IDA, and anemia, respectively. The prevalence of IDA was the highest (20.2%) in adolescents and was significantly different from the prevalence of those participants who were ≥19 years. Furthermore, the prevalence of IDA was significantly low (2.8%) in

[a]Income quantiles: low: ≤5760 ZAR (432.52 USD), intermediate: 5761–14,400 ZAR (432.60–1081.30 USD), and high: >14,400 ZAR (1081.30 USD) on the basis of the study by Hyndman and Fan.[50]

Table 1. **Sociodemography and BMI of South African women ≥15 years of age with measured hemoglobin levels (SANHANES-1)**

	Total participants			Anemia detected[a]		
	N	%	95% CI	*N*	%	95% CI
Total: crude	3177	100.0		652	22.4	20.1–25.0
Total: age-standardized	3177	100.0		652	23.3	21.0–25.8
Age (years)						
15–18	336	10.2	8.8–11.8	91	32.5*≠⊚	25.4–40.6
19–24	476	15.9	13.6–18.5	92	17.8*	13.3–23.6
25–34	558	16.8	14.6–19.3	129	25.9	21.3–31.2
35–44	489	14.5	12.7–16.5	114	25.3	20.3–31.1
45–54	530	16.5	14.1–19.3	94	23.0	17.4–29.8
55–64	406	13.8	11.8–16.0	63	16.9⊚	12.1–23.2
≥65	382	12.3	10.5–14.4	69	17.4≠	12.6–23.5
Race						
Black	2186	83.6	80.5–86.2	498	25.2*	22.5–28.1
White	54	2.6	1.6–4.2	5	7.9*≠	3.0–19.3
Colored	761	11.8	9.7–14.2	99	13.4*≠	10.8–16.4
Indian	153	2.1	1.5–3.1	48	31.7≠	24.2–40.3
Household income (quantile)[b]						
Lower	998	39.4	34.8–44.1	16.0	26.2	22.5–30.4
Intermediate	1072	36.7	32.9–40.8	12.1	22.5	18.6–26.9
Upper	687	23.9	20.6–27.6	8.0	18.9	14.8–23.8
Marital status						
Never married/widowed/separated/ divorced	1618	60.2	56.7–63.5	12.3	22.8	19.7–26.3
Married/living together/civil union	1158	39.8	36.5–43.3	10.6	18.1	14.5–22.4
Highest level of education completed						
No formal schooling/grade 0–7	1034	32.7	29.7–35.9	14.9	23.5*	18.7–29.0
Grade 8–12 (or equivalent)	1680	61.2	57.8–64.5	12.2	22.7≠	19.9–25.7
Tertiary education with or without matriculation (grade 12)	127	6.1	4.3–8.5	7.0	11.4*≠	7.0–18.0
BMI[c,d]						
Underweight	145	3.3	2.6–4.3	34	28.0	20.4–37.0
Normal weight	1002	31.5	29.1–34.1	231	26.0	22.2–30.2
Overweight	758	26.3	24.1–28.6	153	24.3	20.3–28.8
Obese	1135	38.9	36.1–41.7	205	19.0	15.4–23.3

[a]Detected anemia: Hb <12 g/dL as defined by the WHO cutoff used to classify the presence and severity of anemia in females aged ≥15 years on the basis of participants' measured hemoglobin levels.
[b]Household annual income (quantiles): low: ≤5760 ZAR; intermediate: 5761–14,400 ZAR; and upper: 14,401–1,344,001 ZAR.
[c]BMI percentiles for adolescents 15–18 years: underweight: BMI < 5th percentile; normal weight: BMI = 5th–84.9th percentile; overweight: BMI = 85th–94.9th percentile; obesity: BMI ≥ 95th percentile.
[d]BMI categories for adults ≥19 years: underweight: BMI < 18.5 kg/m^2; normal weight: BMI = 18.5–24.9 kg/m^2; overweight: BMI = 25–29.9 kg/m^2; obesity: BMI ≥ 30 kg/m^2.
*≠⊚Matching symbols depict significance between groups as indicated by confidence intervals that do not overlap.

participants who were married, living with partners, or married traditionally (in civil union) when compared with those who were never married or were widowed, separated, or divorced.

Despite the fact that no significant differences were observed for the other factors listed in Table 3, including the dietary intake, the highest prevalence of IDA was observed with participants who consumed green leafy vegetables fewer than four times a week, who did not eat red meat or ate meat with visible fat, and those who had a higher fat scores (10.9%, 15.5%, 11.6%, and 12.3%, respectively).

Table 2. **Multivariate multinomial regression analysis for associations of selected independent household variables with anemia cases in 440 South African households (SANHANES-1)**

Anemia cases within households (HH)	RRR	SE	*t*	*P*
Number of PSUs = 178, *F*(30, 140) = 1.61, Probit: *F* = 0.0354				
Adolescent–adult anemia pair				
Age of HH head (years)				
16–39	*Ref.*			
40–49	1.95	1.65423	0.79	0.433
50–59	0.25	0.256684	–1.35	0.179
60–93	1.81	1.167991	0.91	0.363
Race of HH head				
Non-black	*Ref.*			
Black	22.05	28.24795	2.42	0.017*
Highest education level of HH head				
No formal schooling/less than grade 8 education	*Ref.*			
Completed matriculation (grade 12, possibly completed tertiary education)	4.33	2.532745	2.51	0.013*
Income quantile[a]				
Lower	*Ref.*			
Immediate	0.45	0.532745	–1.51	0.35
Upper	0.75	0.42120	–1.04	0.025*
Locality				
Urban formal	*Ref.*			
Urban informal	3.20	2.899713	1.29	0.2
Rural informal (tribal)	1.43	1.247351	0.41	0.682
Rural formal (farms)	1.24	1.267413	0.21	0.836
Food security				
Food secure	*Ref.*			
At risk of hunger	0.47	0.362874	–0.97	0.331
Experience hunger	0.43	0.342122	–1.06	0.29
_constant	0.00	0.003238	–4.69	0

[a]Household annual income (quantiles): low: ≤5760 ZAR; intermediate: 5761–14,400 ZAR; and upper: 14,401–1,344,001 ZAR. RRR, relative risk.
*Significant difference between groups, as indicated by $P < 0.05$.

Hemoglobin and iron status by age. Disaggregating the data in Table 3 by age (data not shown), the only sociodemographic characteristics that showed significant differences between age groups were marital status and education level. In this case, participants who reported to have never been married or were widowed, separated, or divorced and those who completed grades 8–12 presented with higher prevalence of IDA (8.1% and 8.3%, respectively) compared with their counterparts who were married, living with partners, or in civil union and those who had no formal education (prevalence = 0.3% for both characteristics).

With regard to dietary intake (data not shown), the only significant differences observed were with red meat consumers, as young adults who reported consuming red meat with visible fat had a high prevalence of anemia (33.0% (95% CI: 16.7–54.6)) compared with their counterparts who removed visible fat before consuming meat (4.9% (95% CI: 2.8–8.4)). Moreover, those adolescents and older adults who had high fat scores also presented with significantly higher prevalence of ID (18.1% (95% CI: 8.5–34.7) and 9.0% (95% CI: 2.9–25.0), respectively) compared with their counterparts who had low fat scores (0.4% (95% CI: 0.1–3.0) and 0.9% (95% CI: 0.3–2.6), respectively).

Hemoglobin and iron status by body mass index. Figure 1A shows that, despite no significant differences being observed, overall detected anemia and IDA seemed to decrease with an increase in BMI status of the participants. The highest prevalence

Table 3. **Prevalence of anemia, iron depletion, and iron-deficiency anemia in South African females aged 15–35 years**

	Iron status								
	Normal iron levels		Anemia due to all causes (normal ferritin, low Hb)[a]		Iron depleted (low ferritin, normal Hb)[b]		Iron-deficiency anemia (low ferritin, low Hb)[c]		*N*
	n (%)	95% CI	*n* (%)	95% CI	*n* (%)	95% CI	*n* (%)	95% CI	
Ages 15–35									
Crude	828 (71.4)	67.1–75.4	140 (12.1)	9.8–14.8	52 (6.0)	3.4–10.3	103 (10.5)	8.2–13.4	1123
Age-standardized	828 (70.8)	66.4–74.8	140 (12.5)	10.2–15.2	52 (6.0)	3.5–10.2	103 (10.8)	8.6–13.5	1123
Age									
15–18	150 (59.8)	49.5–69.4	20 (11.2)	5.4–21.8	14 (8.8)	4.3–17.0	38 (20.2)[*⊚]	14.0–28.3	222
19–24	306 (77.6)	71.0–83.1	48 (8.7)	5.8–12.8	22 (6.0)	3.4–10.4	29 (7.8)[*]	4.5–13.0	405
25–35	372 (70.8)	64.9–76.0	72 (15.5)	11.4–20.7	16 (4.9)	1.6–13.7	36 (8.8)[⊚]	5.9–13.1	496
Race									
Black	538 (67.8)	62.9–72.3	108 (13.6)	11.0–16.8	44 (6.9)	3.9–11.8	75 (11.7)	9.1–14.9	765
White	11 (92.7)	65.2–98.9	1 (7.3)	1.1–34.8	0 (0.0)		0 (0.0)		12[d]
Colored	247 (83.3)	78.2–87.4	28 (7.6)	5.0–11.5	5 (1.6)	0.6–4.1	23 (7.5)	4.7–11.9	303
Indian	25 (73.2)	52.1–87.2	2 (7.3)	2.1–22.4	2 (2.4)	0.3–15.5	5 (17.1)	6.5–37.9	34
Household income quantile[e]									
Low	256 (71.1)	65.0–76.5	54 (13.8)	10.3–18.3	11 (4.0)	2.1–7.5	36 (11.0)	7.6–15.8	357
Intermediate	257 (69.6)	61.4–76.7	38 (10.7)	6.7–16.7	17 (7.8)	3.1–18.3	30 (12.0)	7.8–17.9	342
Upper	200 (73.4)	65.0–80.5	22 (9.4)	5.5–15.8	12 (5.8)	2.5–12.8	24 (11.3)	7.0–17.9	258
Marital status									
Never married/widowed/ separated/divorced	457 (70.7)	65.1–75.6	82 (13.3)	9.9–17.7	33 (4.8)	2.8–8.1	69 (11.2)[*]	8.1–15.4	641
Married/living together/ civil union	210 (84.3)	78.5–88.7	32 (8.5)	5.1–13.8	7 (4.4)	1.3–14.4	14 (2.8)[*]	1.4–5.4	263
Highest level of education completed									
No formal schooling/grade 0–7	124 (75.3)	63.7–84.1	24 (13.8)	8.2–22.2	7 (4.5)	1.9–10.4	8 (6.4)	2.7–14.4	163
Grade 8–12 (or equivalent)	591 (69.3)	64.0–74.1	98 (12.4)	9.9–15.5	37 (6.6)	3.4–12.4	85 (11.7)	9.0–15.2	811
Tertiary education with/without matriculation (grade 12)	32 (87.9)	74.9–94.6	3 (5.5)	1.3–21.0	3 (4.6)	1.4–13.5	2 (2.1)	0.4–11.1	40
Green leafy vegetable consumption									
<4 times a week	599 (70.9)	66.1–75.3	104 (12.0)	9.3–15.5	34 (6.1)	2.9–12.5	75 (10.9)	8.3–14.3	812
≥4 times a week	156 (70.0)	61.3–77.5	29 (16.1)	9.6–25.7	14 (5.6)	3.1–9.9	22 (8.2)	4.4–14.8	221
Red meat consumption									
Do not eat red meat	36 (65.3)	46.8–80.2	7 (11.6)	4.6–26.3	4 (7.6)	2.4–21.4	6 (15.5)	6.7–31.9	53
Meat with fat on	541 (71.4)	66.8–75.5	89 (10.9)	8.3–14.2	38 (6.2)	3.5–10.6	72 (11.6)	8.6–15.3	740
Fat removed from the meat	180 (68.6)	57.8–77.7	37 (19.5)	13.2–27.9	6 (4.5)	1.6–12.2	20 (7.3)	4.1–12.7	243
Fat score									
Low: 0–7	406 (73.5)	67.9–78.5	70 (14.0)	10.4–18.5	19 (2.9)	1.5–5.5	45 (9.6)	6.6–13.6	540
Medium–high: 8–20	325 (67.6)	61.4–73.2	59 (11.2)	7.4–16.5	27 (8.9)	4.9–15.9	49 (12.3)	8.8–17.0	460

[a]Anemia due to all causes: ferritin ≥ 15 μg/mL and Hb < 12 g/dL.
[b]Iron depleted: ferritin < 15 μg/mL and Hb ≥ 12 g/dL.
[c]Iron-deficiency anemia: ferritin < 15 μg/mL and Hb < 12 g/dL.
[d]Estimates based on sample sizes <30 should be interpreted with caution.
[e]Household annual income (quantiles): low: ≤5760 ZAR; intermediate: 5761–14,400 ZAR; and upper: 14,401–1,344,001 ZAR.
[*⊚]Matching symbols depict significance between groups, as indicated by confidence intervals that do not overlap; %, weighted prevalence.

of anemia and IDA in this case was observed in the underweight participants (30.4% and 20.9%, respectively), while the lowest was observed in obese participants (18.7% and 3.9%, respectively). Upon disaggregating the data by age groups (Fig. 1B), the highest prevalence of anemia, ID, and IDA in adolescents and older adults was observed in those who were overweight, while the lowest prevalence was observed in those who were obese. In the young adult group, overweight participants tended to have a lower prevalence of anemia, ID, and IDA than their obese counterparts.

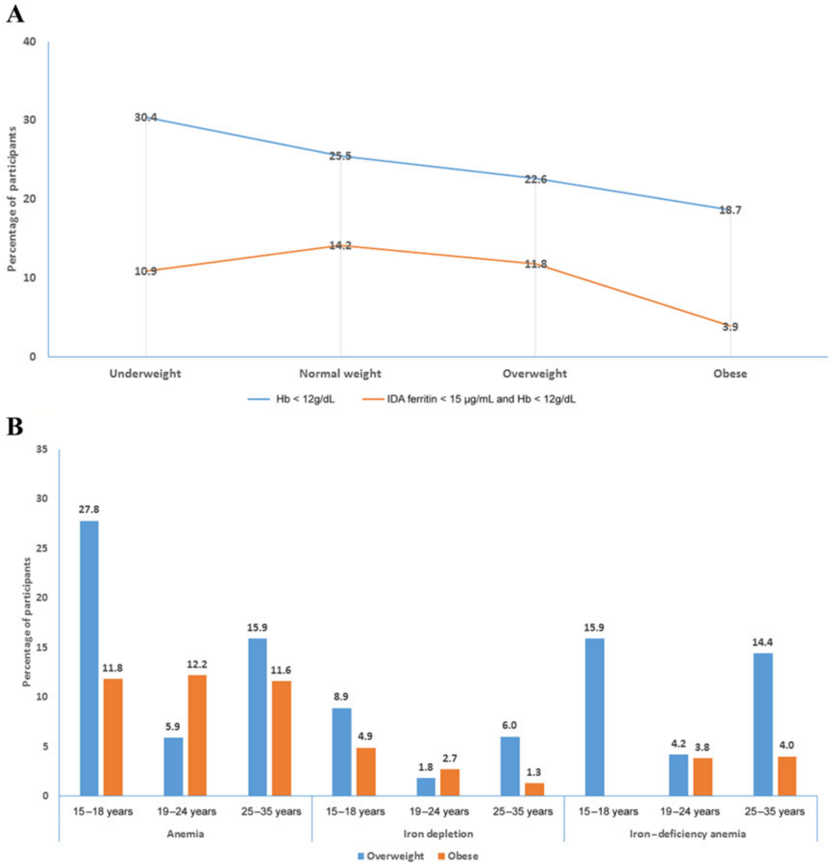

Figure 1. (A) Prevalence of anemia and iron-deficiency anemia versus BMI in South African women ≥15 years of age. (B) Prevalence of anemia, iron depletion, and iron-deficiency anemia versus BMI in adolescents.

Predictors of anemia and iron deficiency based on bivariate logistic regression analysis. Table 4 shows that the only predictors of anemia observed were the age, ethnicity, BMI levels, household income, and education level of the participants. Having completed grades 8–12 increased the chances of participants presenting with IDA (odds ratio (OR) = 2.70, $P = 0.044$). Being a black South African also increased the chances of being anemic and presenting with ID (OR = 1.53, $P = 0.005$ and OR = 3.06, $P = 0.010$, respectively). Being older, belonging to an upper income household, and being obese, on the other hand, decreased the chances of having ID, anemia, and IDA (OR values < 0.1, all P values < 0.05).

Predictors of anemia and iron deficiency disaggregated by age and based on bivariate and multiple logistic regression.

Adolescents (15–18 years). On analyzing the predictors of anemia in adolescents (Table 5), it was observed that both the bivariate and multiple logistic regressions suggested that overweight adolescents were almost three times more likely to be anemic (ORs = 2.68 and 2.67, both P values = 0.011) when compared with their normal-weight counterparts. Upon repeating these regression analyses (bivariate and multiple logistic regressions) to identify the predictors of ID in adolescents, Table 6 shows that, while the consumption of red meat with visible fat removed was protective of adolescents becoming iron depleted (OR = 0.1, $P = 0.036$ and OR = 0.11, $P = 0.04$, respectively); having a high fat score increased their chances of becoming ID by more than 50-fold (OR = 52.35, $P = <0.01$ and OR = 54.06, $P = 0.001$, respectively). We conducted the same regression analyses to identify predictors of IDA in adolescents, and Table 7 shows that none of

Table 4. Predictors of anemia, iron depletion, and iron-deficiency anemia in South African women aged 15–35 years: bivariate logistic regression

	Anemia detected: all cause			Iron depletion			Iron-deficiency anemia		
	Odds ratio	95% CI	*P*	Odds ratio	95% CI	*P*	Odds ratio	95% CI	*P*
Age									
Young <18 years	*Ref.*								
Older ≥19 years	0.99	0.99–1.00	0.074	0.94	0.88–0.99	**0.020**	0.98	0.93–1.04	0.468
Race									
Non-black	*Ref.*								
Black	1.53	1.14–2.07	**0.005***	3.06	1.30–7.21	**0.010***	1.4	0.75–2.74	0.279
BMI[a,b]									
Normal weight	*Ref.*								
Underweight	1.11	0.66–1.86	0.704				1.19	0.40–3.51	0.752
Overweight	0.79	0.59–1.06	0.116				0.67	0.34–1.30	0.238
Obesity	0.73	0.56–0.95	**0.021***				0.39	0.18–0.88	**0.022***
Marital status									
Never married/widowed/ separated/divorced	*Ref.*								
Married/living together/civil union	0.88	0.69–1.11	0.268						
Household income quantile[c]									
Low	*Ref.*								
Intermediate	0.86	0.67–1.11	0.247						
Upper	0.74	0.54–1.01	**0.045***						
Education level completed									
No schooling/primary school	*Ref.*								
Grades 8–12							2.70	1.03–7.10	**0.044***
Tertiary							1.49	0.24–9.22	0.667

[a]BMI percentiles for adolescents 15–18 years: underweight: BMI < 5th percentile; normal weight: BMI = 5th–84.9th percentile; overweight: BMI = 85th–94.9th percentile; obesity: BMI ≥ 95th percentile.
[b]BMI categories for adults ≥19 years: underweight: BMI < 18.5 kg/m^2; normal weight: BMI = 18.5–24.9 kg/m^2; overweight: BMI = 25–29.9 kg/m^2; obesity: BMI ≥ 30 kg/m^2.
[c]Household annual income (quantiles): low: ≤5760 ZAR; intermediate: 5761–14,400 ZAR; and upper: 14,401–1,344,001 ZAR.
*, tending to significance.

the participants' characteristics and diet behaviors resulted in adolescents presenting with IDA.

Young adults (19–24 years). Table 5 also shows that, according to the bivariate logistic regression, overweight and obese young adults were less likely to be anemic (both ORs were less than 0.5 and the *P* values were <0.05) compared with their normal-weight counterparts. The multiple logistic regression also showed that overweight young adults were less likely to be anemic (OR = 0.32, *P* = 0.033). As shown by both bivariate and multiple logistic regressions, being married and completing tertiary education also seemed to be protective against young adults becoming anemic (OR = 0.25, *P* = 0.008 and OR = 0.15, *P* = 0.003 for marital status and OR = 0.05, *P* = 0.015 and OR = 0.04, *P* = 0.011 for tertiary education, respectively). Table 6 also shows that both bivariate and multiple logistic regressions suggested that being a black young adult increased the chances of ID by 28.80- and 39.79-fold, respectively (both *P* values < 0.001). The bivariate logistic regression also showed that presenting with abnormal BMI levels was protective of young adults becoming ID (OR values < 0.25, *P* values < 0.05). The multiple logistic regression showed that being an obese young adult was most protective of becoming ID (OR = 0.05, *P* = 0.04). As shown in Table 7, both bivariate and multiple logistic regressions suggested that, while being obese and being married were protective of young adults presenting with IDA (OR = 0.16, *P* = 0.009 and OR = 0.24, *P* = 0.007 for obesity; OR = 0.06, *P* = 0.01 and OR = 0.07, *P* = 0.017 for marital status); completing grades 8–12 increased the chances of young adults presenting with IDA by 15.14- and 11.25-fold, respectively (both *P* values were <0.04).

Table 5. Predictors of anemia in South African women aged 15–35 years: bivariate and multiple logistic regression

	Anemia (hemoglobin)																	
	15–18 years						19–24 years						25–35 years					
	Bivariate logistic			Multiple logistic			Bivariate logistic			Multiple logistic			Bivariate logistic			Multiple logistic		
	OR	95% CI	*P* value	AOR	95% CI	*P* value	OR	95% CI	*P* value	AOR	95% CI	*P* value	OR	95% CI	*P* value	AOR	95% CI	*P* value
Age	1.06	0.79–1.42	0.708	1.04	0.8–1.36	0.77	0.86	0.72–1.03	0.095	0.96	0.76–1.2	0.707	0.99	0.98–1	**0.009**	0.99	0.98–1	**0.034**
Race																		
Non-black	*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—
Black	1.7	0.86–3.35	0.127	1.77	0.84–3.71	0.131	1.32	0.62–2.8	0.467	1.43	0.61–3.32	0.408	1.77	1.26–2.49	**0.001**	1.81	1.26–2.59	**0.001**
BMI[a, b]																		
Normal weight	*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—
Underweight	1.26	0.27–5.9	0.771	1.37	0.29–6.35	0.687	1.14	0.35–3.65	0.828	1.37	0.34–5.6	0.659	1.35	0.65–2.81	0.425	1.38	0.65–2.92	0.399
Overweight	2.68	1.25–5.74	**0.011**	2.67	1.25–5.71	**0.011**	0.34	0.14–0.81	**0.015**	0.32	0.11–0.91	**0.033**	0.83	0.58–1.2	0.325	0.82	0.57–1.18	0.289
Obesity	0.7	0.2–2.44	0.574	0.68	0.2–2.37	0.544	0.46	0.21–0.99	**0.047**	0.43	0.17–1.11	0.081	0.71	0.5–1	0.052	0.71	0.5–1.01	0.057
Married household income quantile[c]							0.25	0.09–0.69	**0.008**	0.15	0.04–0.52	0.003	1.09	0.75–1.6	0.638			
Low	*Ref.*	—	—				*Ref.*	—	—				*Ref.*	—	—			
Intermediate	0.61	0.29–1.32	0.209				0.64	0.28–1.47	0.292				0.82	0.55–1.2[illegible]	0.334			
Upper	0.43	0.14–1.31	0.136				0.52	0.23–1.14	0.1				0.74	0.48–1.14	0.17			
Education level completed																		
No schooling/primary school							*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—			
Grades 8–12							1.39	0.46–4.16	0.558	1.07	0.33–3.47	0.907	1.12	0.78–1.61	0.53			
Tertiary							0.05	0–0.55	**0.015**	0.04	0–0.47	**0.011**	0.67	0.31–1.45	0.304			
Green leafy vegetables (< 4 days/week versus ≥4 days/week)	1.63	0.64–4.11	0.302				1.47	0.77–2.82	0.243				1.18	0.75–1.8[illegible]	0.467			
Red meat																		
Do not eat red meat	*Ref.*	—	—				*Ref.*	—	—				*Ref.*	—	—			
Eat meat with fat	0.91	0.25–3.25	0.88				0.86	0.22–3.45	0.834				0.72	0.4–1.31	0.284			
Eat meat with fat removed	1.53	0.26–8.85	0.636				1.16	0.27–5.07	0.84				0.56	0.29–1.1	0.095			
High fat score versus low fat score	1	0.45–2.21	0.991				1.2	0.61–2.39	0.593				1.22	0.82–1.8	0.328			

[a]BMI percentiles for adolescents 15–18 years: underweight: BMI < 5th percentile; normal weight: BMI = 5th–84.9th percentile; overweight: BMI = 85th–94.9th percentile; obesity: BMI ≥ 95th percentile.
[b]BMI categories for adults ≥19 years: underweight: BMI < 18.5 kg/m^2; normal weight: BMI = 18.5–24.9 kg/m^2; overweight: BMI = 25–29.9 kg/m^2; obesity: BMI ≥ 30 kg/m^2.
[c]Household annual income (quantiles): low: ≤ 5760 ZAR; intermediate: 5761–14,400 ZAR; and upper: 14,401–1,344,001 ZAR.

Older adults (25–35 years). Finally, Table 5 shows that the bivariate and multiple logistic regressions suggested that black older adults had increased chances of becoming anemic by almost twofold (OR values = 1.77 and 1.81, both *P* values = 0.001). Moreover, as shown in Table 6, while being an obese older adult was protective of ID (OR = 0.16, *P* = 0.04) (as shown by the bivariate logistic regression), having a high fat score increased the chances of these women becoming ID by 11.09-fold (*P* = 0.005) and 10.72-fold (*P* = 0.007) (as shown by both the bivariate and multiple logistic regressions, respectively). As shown by both bivariate and multiple logistic regressions, being a black older adult increased the chances of presenting with IDA by 3.72-fold (*P* = 0.014) and 4.36-fold (*P* = 0.011) (Table 7). However, the bivariate logistic regression showed that consumption of green leafy vegetables four times or more each week and removing visible fat before consuming red meat were protective of older adults presenting with IDA (OR = 0.36, *P* = 0.038 and OR = 0.31, *P* = 0.029, respectively) (Table 7).

Confounders of anemia

It has to be noted that data on anemia presented in this analysis have to be interpreted with caution, bearing in mind that the South African population is battling both infectious diseases (e.g., TB and HIV) and NCDs (e.g., hypertension and diabetes). Moreover, despite the fact that malaria is not common in the country, individuals residing in rural and informal urban communities are exposed to various parasites (including nematodes) owing to their lack of access to decent sanitary services (flushing toilets, in particular).[32] Investigating the aforementioned challenges is beyond the scope of the current research; however, when we closely examined participants who had valid data on serum glucose, BP, and CRP levels, we observed that 2675 (84.0%), 767 (27.5%), and 1844 (63.1%) had CRP detected in their blood, abnormal HbAlc levels (i.e., had uncontrolled blood glucose levels), and DBP and SBP values that were above normal (i.e., were pre- and hypertensive), respectively (data not shown). We also observed a trend of increased anemia

Table 6. Predictors of iron depletion in South African women 15–35 years: bivariate multiple logistic regression

	Iron depletion (low ferritin, normal hemoglobin)																	
	15–18 years						19–24 years						25–35 years					
	Bivariate logistic			Multiple logistic			Bivariate logistic			Multiple logistic			Bivariate logistic			Multiple logistic		
	OR	95% CI	*P* value	AOR	95% CI	*P* value	OR	95% CI	*P* value	AOR	95% CI	*P* value	OR	95% CI	*P* value	AOR	95% CI	*P* value
Age	1.12	0.46–2.74	0.794	1.29	0.54–3.1	0.566	0.76	0.58–0.98	**0.037**	0.55	0.4–0.77	**0.001**	0.97	0.75–1.26	0.81	0.99	0.78–1.26	0.943
Race																		
Non-black	*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—
Black	3.56	0.72–17.68	0.12	2.4	0.47–12.35	0.293	28.8	5.93–139.83	**< 0.001**	39.79	6.07–260.94	**<0.001**	3.78	0.65–21.82	0.137	4.06	0.56–29.47	0.165
BMI[a, b]																		
Normal weight	*Ref.*	—	—				*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—
Underweight	1						0.04	0–0.39	**0.005**	0.25	0.03–2.19	0.21	0.77	0.07–9	0.837	1.17	0.07–19.73	0.913
Overweight	0.87	0.16–4.7	0.872				0.23	0.07–0.84	**0.026**	0.57	0.16–2.08	0.396	0.82	0.35–1.9	0.64	0.79	0.31–2.01	0.622
Obesity	0.46	0.05–4.35	0.496				0.08	0.01–0.46	**0.005**	0.05	0–0.87	**0.04**	0.16	0.03–0.92	**0.04**	0.2	0.04–1.1	0.063
Married household income quantile[c]													3.47	0.48–24.99	0.216			
Low	*Ref.*	—	—				*Ref.*	—	—				*Ref.*	—	—			
Intermediate	1.02	0.14–7.13	0.988				3.51	0.56–22.02	0.179				2.25	0.27–18.45	0.449			
Upper	0.55	0.1–3.01	0.49				1.72	0.28–10.71	0.56				2.3	0.28–19.08	0.438			
Education level completed																		
No schooling/primary school							*Ref.*	—	—				*Ref.*	—	—			
Grades 8–12							0.63	0.15–2.55	0.513				10.29	0.95–111.01	0.055			
Tertiary							0.48	0.04–6.28	0.571				11.71	0.98–140.28	0.052			
Green leafy vegetables (<4 days/week versus ≥4 days/week)	1.05	0.23–4.89	0.949				1.67	0.44–6.36	0.449				0.41	0.07–2.48	0.332			
Red meat																		
Do not eat red meat/eat meat with fat	*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—				*Ref.*	—	—			
Eat meat with fat removed	0.1	0.01–0.86	**0.036**	0.11	0.01–0.96	**0.046**	0.77	0.19–3.09	0.714				1.42	0.4–4.97	0.584			
Red meat																		
Do not eat red meat							*Ref.*	—	—				*Ref.*	—	—			
Eat meat with fat							0.21	0.03–1.36	0.101				1.06	0.1–10.7	0.961			
Eat meat with fat removed							0.17	0.02–1.39	0.099				1.5	0.09–24.35	0.776			
High fat score versus low fat score	52.35	5.88–465.82	**<0.001**	54.06	5.93–492.75	**0.001**	0.4	0.1–1.63	0.2				11.09	2.07–59.34	**0.005**	10.72	1.93–59.59	**0.007**

[a]BMI percentiles for adolescents 15–18 years: underweight: BMI < 5th percentile; normal weight: BMI = 5th–84.9th percentile; overweight: BMI = 85th–94.9th percentile; obesity: BMI ≥ 95th percentile.
[b]BMI categories for adults ≥19 years: underweight: BMI < 18.5 kg/m^2; normal weight: BMI = 18.5–24.9 kg/m^2; overweight: BMI = 25–29.9 kg/m^2; obesity: BMI ≥ 30 kg/m^2.
[c]Household annual income (quantiles): low: ≤5760 ZAR; intermediate: 5761–14,400 ZAR; and upper: 14,401–1,344,001 ZAR.

prevalence with increasing serum CRP levels (i.e., 18.3% for CRP < 1, 19.7% for CRP = 1–3, and 22.1% for CRP > 3).

Discussion

The current study shows that the prevalence of anemia in South African women of reproductive age seems to have more than halved (12.5% compared with 29.4% in 2005).[13] This prevalence is also less than half of the mean prevalences of 29.4%, 34.0%, 38.3%, 40.0%, 45.5%, and 38.6% observed in women of reproductive age in Brazil, the Dominican Republic, Bolivia, Panama, Haiti, and Africa, respectively, as identified by Mujica-Coopman *et al.*[33] and the WHO[34] in 2011. The WHO also highlighted that the Sub-Saharan African countries recorded a prevalence of 20–39.9%, while the West African countries had the highest prevalence (above 40%). Mujica-Coopman *et al.*[33] also showed that anemia is a mild public health problem in Chile, Columbia, Salvador, Costa Rica, and Nicaragua, as indicated by mean prevalences that range from 5.1% to 11.2% in these countries. While the prevalence of ID in SA seems to have improved marginally from 7.7% in 2005 to 6.0% in 2012, the prevalence of IDA appears to be stable (10.8% compared with 10.5% in 2005).[13] However, it is important to note that, despite the presence of communicable (HIV/AIDS and TB) and NCDs in the country, the prevalences of anemia, ID, and IDA are still lower than those for women of reproductive age in other African countries, like Ethiopia,[35] where the mean prevalences for anemia, ID, and IDA were recorded to be 29.4%, 32.1%, and 18.0%, respectively, in 2009. It is also important to note that the comparisons made above should be interpreted with caution given the different research designs of these surveys.

We may, however, want to credit the improvement in anemia and iron status of women in SA to the intervention program mentioned earlier,

Table 7. **Predictors of iron-deficiency anemia in South African women 15–35 years: bivariate multiple logistic regression**

	Iron-deficiency anemia (low ferritin, low hemoglobin)																	
	15–18 years						19–24 years						25–35 years					
	Bivariate logistic			Multiple logistic			Bivariate logistic			Multiple logistic			Bivariate logistic			Multiple logistic		
	OR	95% CI	*P* value	AOR	95% CI	*P* value	OR	95% CI	*P* value	AOR	95% CI	*P* value	OR	95% CI	*P* value	AOR	95% CI	*P* value
Age	0.94	0.56–1.59	0.826	0.91	0.51–1.6	0.732	0.89	0.68–1.16	0.388	0.97	0.74–1.26	0.796	1.21	1.02–1.43	**0.029**	1.25	1.06–1.47	**0.009**
Race																		
Non-black	*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—
Black	1.15	0.46–2.91	0.759	1.2	0.47–3.11	0.7	0.8	0.25–2.53	0.698	0.92	0.29–2.94	0.884	3.72	1.31–10.54	**0.014**	4.36	1.41–13.49	**0.011**
BMI[a,b]																		
Normal weight	*Ref.*	—	—				*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—			
Underweight	0.38	0.07–2.01	0.251				1.64	0.3–8.89	0.564	1.84	0.33–10.41	0.487	1[#]					
Overweight	1.08	0.37–3.16	0.882				0.35	0.08–1.63	0.181	0.37	0.06–2.3	0.281	1.36	0.47–3.96	0.569			
Obesity	0.39	0.07–2.11	0.274				0.16	0.04–0.64	**0.009**	0.24	0.05–1.13	**0.007**	0.35	0.11–1.12	0.078			
Married household income quantile[c]							0.06	0.01–0.52	**0.01**	0.07	0.01–0.61	**0.017**	0.66	0.22–1.95	0.445			
Low	*Ref.*	—	—				*Ref.*	—	—				*Ref.*	—	—			
Intermediate	0.64	0.25–1.64	0.347				0.45	0.09–2.4	0.35				1.97	0.68–5.72	0.209			
Upper	1.01	0.27–3.71	0.992				0.75	0.21–2.72	0.66				1.25	0.32–4.84	0.745			
Education level completed																		
No schooling/primary school							*Ref.*	—	—	*Ref.*	—	—	*Ref.*	—	—			
Grades 8–12							15.14	1.78–128.84	**0.013**	11.25	1.19–106.01	**0.035**	3.06	0.74–12.58	0.121			
Tertiary							1.58	0.08–32.63	0.766	1.16	0.05–24.94	0.924	1.35	0.12–15.5	0.811			
Green leafy vegetables (<4 days/week versus ≥4 days/week)	0.92	0.2–4.27	0.919				1.29	0.43–3.89	0.654				0.36	0.13–0.94	**0.038**	0.36	0.13–1.06	0.063
Red meat																		
Do not eat red meat/eat meat with fat	*Ref.*	—	—				*Ref.*	—	—				*Ref.*	—	—	*Ref.*	—	—
Eat meat with fat removed	0.79	0.23–2.74	0.713				0.75	0.19–3.04	0.687				0.31	0.11–0.89	**0.029**	0.39	0.12–1.22	0.104
Red meat																		
Do not eat red meat	*Ref.*	—	—				*Ref.*	—	—				*Ref.*	—	—			
Eat meat with fat	0.34	0.06–2.01	0.231				1.06	0.12–9.67	0.961				2.27	0.56–9.29	0.252			
Eat meat with fat removed	0.3	0.04–2.55	0.267				0.79	0.07–8.97	0.85				0.68	0.14–3.37	0.633			
High fat score versus low fat score	1	0.35–2.89	0.993				1.8	0.55–5.83	0.328				1.76	0.71–4.32	0.219			

[a]BMI percentiles for adolescents 15–18 years: underweight: BMI < 5th percentile; normal weight: BMI = 5th–84.9th percentile; overweight: BMI = 85th–94.9th percentile; obesity: BMI ≥ 95th percentile.
[b]BMI categories for adults ≥19 years: underweight: BMI < 18.5 kg/m^2; normal weight: BMI = 18.5–24.9 kg/m^2; overweight: BMI = 25–29.9 kg/m^2; obesity: BMI ≥ 30 kg/m^2.
[c]Household annual income (quantiles): low: ≤5760 ZAR; intermediate: 5761–14,400 ZAR; and upper: 14,401–1,344,001 ZAR.

especially the NSNP[17] and the FFP,[16] which include nonpregnant women of reproductive age. More importantly, the FFP choice of food vehicles (i.e., staple foods such as maize meal and flour) is possibly reaching many South Africans, even in the remote rural areas. Prior studies have associated the Hb levels of Africans with a multitude of factors, such as food and nutrition insecurity, suboptimal diets as a result of poverty due to socioeconomic deprivation, and infection due to chronic and/or infectious diseases.[5,7,8,14] It was therefore important to investigate the changes in the prevalence of anemia, ID, and IDA over the past 10 years. Moreover, it was important to identify their determinants in a nationally representative sample of South African women of childbearing age and investigate the effect of BMI and dietary intake on these conditions.

The major outcome of the current analyses magnified sociodemographic factors, such as age (being young), belonging to the black ethnic group, not having a partner (i.e., never married, being widowed, separated, or divorced), attending tertiary education, and residing in households with a reported low income, as factors that fuel anemia in the country. In the current analyses, it is also clear that all forms of anemia are common in the adolescent group. Overconsumption of dietary fat and excess body weight have been identified as the major contributors to anemia and low iron status in the adolescent group. In fact, removing visible fat from meat before consumption has been shown to be protective against ID. It is also important to note that, while being overweight in adolescence increases the chances of becoming anemic by at least 2.6-fold; being overweight and obese in adulthood (19–35 years) seems to be protective against ID and IDA. In the younger adult group (19–24 years), ethnicity and education levels also influence ID and IDA: black South Africans and those who have completed grades 8–12 were up to 40 and 15 times more likely to have ID or IDA, respectively. However, it appears that getting married or being overweight or obese is protective of becoming anemic or presenting with ID or IDA in this age group. Finally, it seems as though being a black older adult (25–35 years) in SA increases the risk of being anemic and presenting with IDA by up to fourfold.

In trying to understand the presentation of anemia in different age groups in the country, it is important to note that the diet of adolescents is not optimal. In fact, starting from the early age of adolescence, the foods that this group relies on for most of the day (i.e., foods carried to school in their lunch boxes) comprise white bread with processed meat such as polony (bologna), which is easily accessible and cheap in South African food outlets, but is also high in fat and deficient in iron.[36] Abrahams *et al.*[36] further showed that most children who do not carry lunch boxes to school rely on the foods sold by street vendors as well as the foods available in their school tuckshops (cafeterias). Moreover, the majority of foods sold in the streets of SA do not promote good health, as shown in a study by Mchiza *et al.*[37] These foods are often high in sugar and fat and low in micronutrients by virtue of being processed and the preparation methods used. South African adolescents mostly choose high-fat foods, such as crisps or chips and fat cakes, from the street vendors and cafeterias instead of whole and nourishing foods.[36,38] The majority of South African adolescents (14–18 years) who choose these kinds of foods often present with micronutrient deficiencies, overweight, and obesity.[39]

There is also an expanding body of knowledge globally that suggests that being overweight in adolescence affects iron homeostasis. In fact, Wenzel *et al.*[40] and Seltzer *et al.*[41] have long shown a strong correlation between decreased serum iron levels and increased adiposity in adolescents. Decades later, Nead *et al.*[42] confirmed that overweight children and adolescents who participated in the National Health and Nutritional Examination Survey III, (USA), were twice as more likely to have ID, on the basis of abnormal ferritin levels, compared with their normal weight counterparts. Similar results were reported in a cross-sectional study of 321 Israeli children and adolescents. In this study, children who presented with a BMI above the 85th percentile were shown to be 1.75 times more likely to have decreased serum iron levels than those below this BMI threshold. Moreover, Tussing-Humphrey *et al.*[43] showed that ID is positively associated with BMI and inflammation (as measured by CRP). The results of the current study corroborate these findings, as the prevalence of anemia tended to increase with an increase in CRP levels. This could be a possible explanation for the current findings that suggest that overweight in adolescence increases the risk of anemia by up to twofold.

The majority of South African young adults (19–24 years), on the other hand, are at the highest risk of nutrient deficiencies, as the majority have completed their schooling and either attend tertiary institutions or are unemployed. In this regard, the SANHANES-1 data lend support to this concept, in the sense that only 20% of South African young adults (ages 19–24 years) are employed and the rest (80%) are either at tertiary institutions or unemployed (data not shown). These young adults therefore rely on money provided by their parents or household heads for food. The majority of the household heads in the current analyses have been shown to be poorer and black, therefore increasing cases of anemia in their households. In addition, it should be noted that the majority of South African young adults also rely on food that they purchase from street vendors.[38] In fact, Hill *et al.*[38] have shown that 29% of consumers of street food in SA fall between the ages of 18 and 24 years and have completed grade 12. On the other hand, Mchiza *et al.*[37] showed that, despite the most popular street food in this age group being high in visible fat and served in large portion sizes; some of it is rich in iron (i.e., includes large portion sizes of red meat, chicken, and beef liver, as well as green leafy vegetables). This could therefore explain the current findings that being overweight and obese appear to be protective against anemia, ID, and IDA in young adults. Similar findings were published by Chang *et al.*,[44] who reported that BMI in ≥19-year-old women participating in the third Nutrition and Health Survey in Taiwan (NAHSIT) 2005–2008 had a protective effect against IDA. In fact, the authors also showed that the IDA–overweight relationship resulted in an OR of 0.365 (95% CI: 0.181–0.736) and the IDA–obese relationship resulted in an OR of 0.480 (95% CI: 0.259–0.891) compared with normal-weight peers.

Similarly, the majority (39%) of adult (25–35-year old) South Africans also choose the aforementioned iron-rich street foods;[38] hence, overweight and obesity in this age group also appears to be protective against anemia and ID in some of the participants. However, it is also important to note that ethnicity in this age group is an important factor, as it explains the income status of these individuals. In fact, the majority of black South Africans are poorer (i.e., they are in the lower socioeconomic segment of the population). Poorer people in SA tend to choose cuts of meat with lots of visible fat.[45] These cuts of meat weigh less per unit cost; hence, they are cheaper to purchase. Purchasing this fat as part of the meat translates to it being consumed. What is notable in the current research is that consuming visible fat in the meat increased chances of ID by up to 11-fold. These results are consistent with those of Chang *et al.*,[44] who also showed, in the univariate analysis they conducted for data from ≥19-year-old women participating in the third NAHSIT study, that dietary fat increased the risk of IDA in overweight/obese women by 10-fold (i.e., OR: 10.119, 95% CI: 1.267–80.79).

In summary, the highlight of the current research is that South African adolescents are at the greatest risk of anemia, as determined by their body size and the quality of diet they consume. South African young and older adults who have completed grades 8–12 and those who are black, poorer, and overconsume dietary fat are also at risk of anemia. However, it seems that a higher BMI in adulthood in SA is protective against anemia. These outcomes are suggestive of needed targeted intervention programs to prevent and treat micronutrient deficiencies (anemia and iron status, in particular) in South African women. They also provide concise evidence as to the most opportune time to implement these interventions in the country.

Interventions that should be targeted to adolescents at their early adolescent stage include scaling up and monitoring the NSNP by the South African government to reach all needy secondary schools in SA. More importantly, a policy to regulate sales of unhealthy foods and snacks in school cafeterias and from school vendors should be developed. Schools should also scale up health education classes that emphasize the importance of a healthy BMI and nutrition knowledge (i.e., knowledge regarding good food sources of essential vitamins and minerals and the importance of consuming fruits and vegetables while avoiding sugary and fatty foods, especially visible fat in meat). There are also other important interventions that need to be directed to young adults. These include an extension of subsidies for vulnerable unemployed young adults in the form of social grants and tertiary education bursaries. Finally, it seems that ethnic inequalities continue to persist in SA, with the majority of black women of reproductive age (especially older adults) still belonging to or heading households with less income and financial constraints. Employment opportunities for women in the public, private, and informal sectors should be scaled up in the country. This could improve women's food-purchasing power and access to relevant nutrition education.

Despite the strengths of the presented outcomes of this study, there are limitations that call for caution in generalizing the findings of the current study to the entire South African population. One of the limitations was the diagnosis of anemia on the basis of Hb and serum ferritin levels only. This is limiting in identifying poor iron status due to factors other than associated with dietary practices. Nevertheless, this limitation should be seen against the current knowledge that "at least half" of anemia prevalence globally is due to malnutrition in countries grappling with food shortages or limited access to nutritionally balanced foods.[46] Another limitation for this study is that the SANHANES-1 was a household survey designed to select participants on the basis of their geographic location, gender, and ethnicity across the entire age spectrum. As such, the total sample we obtained may not be a true representative sample of our target population, namely, women of reproductive age. The observed data can, however, guide addressing priorities in this vulnerable population group, since anemia is known to increase with parity.[47] We did not investigate parity in this group of participants, and this calls for further studies to investigate parity to increase better understanding about anemia and iron status of South African women who bear one or more children. Evidence also supports the concept that appropriate iron supplementation of women of reproductive age improves the survival of these women during childbirth, prepares them to carry their babies to term without complications,[48] and enables them to enter pregnancy with iron stores of ≥300 mg to be able to provide their needs and those of their unborn babies.[49] This therefore calls for further studies that will address the aforementioned limitations of the current study to provide a more comprehensive picture of the determinants of anemia and micronutrient deficiencies in the country.

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Competing interests

The authors declare no competing interests.

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