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Association of dietary patterns with hemoglobin levels among pregnant women in Asahan Regency

Hubungan pola makan dengan kadar hemoglobin pada ibu hamil di Kabupaten Asahan

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Abstract

Anemia during pregnancy is a serious public health issue that can adversely affect both mothers and fetuses. Dietary patterns play a crucial role in determining the hemoglobin levels in pregnant women. In Indonesia, anemia among pregnant women remains highly prevalent, affecting approximately 48.9% of them. This study aimed to analyze the association between dietary patterns and hemoglobin levels in pregnant women. This study employed a cross-sectional design with a purposive sampling technique, involving 170 pregnant women in Asahan Regency from April to May 2025. Dietary data were collected using a semi-quantitative food frequency questionnaire (SQ-FFQ), and hemoglobin levels were measured using a hematology analyzer. Multivariate regression analysis was performed to examine the association between each dietary pattern and the hemoglobin level. Dietary patterns high in both animal and plant protein were significantly associated with increased hemoglobin levels in pregnant women (95% CI: 12.02–12.7; p<0.001). Conversely, consumption of diets high in sugar and fat was significantly associated with decreased hemoglobin levels (95% CI: 11–11.8; p<0.001). In conclusion, diets rich in animal and plant proteins are positively associated with higher hemoglobin levels in pregnant women. These findings highlight the importance of protein-based nutritional interventions in preventing anemia during pregnancy.

Keywords: Anemia, dietary pattern, hemoglobin levels, pregnant women, principal component analysis

Abstrak

Anemia pada kehamilan merupakan masalah kesehatan masyarakat yang serius dan dapat berdampak buruk terhadap ibu maupun janin. Di Indonesia, prevalensi anemia pada ibu hamil masih tinggi yaitu sekitar 48,9%. Penelitian ini bertujuan untuk menganalisis hubungan antara pola makan dengan kadar hemoglobin ibu hamil. Studi ini menggunakan desain *cross sectional* dengan teknik pengambilan sampel *purposive sampling*, melibatkan 170 ibu hamil di Kabupaten Asahan selama April–Mei 2025. Data mengenai pola makan dikumpulkan menggunakan semi-quantitative food frequency questionnaire (SQ-FFQ) dan kadar hemoglobin diukur dengan metode hematology analyzer. Uji regresi multivariat dilakukan untuk mengukur hubungan pada setiap pola makan dengan kadar hemoglobin. Pola makan tinggi protein hewani dan nabati berhubungan signifikan dengan peningkatan kadar hemoglobin ibu hamil (95% CI: 12.02–12.7; p<0,001). Konsumsi pola makan tinggi gula dan lemak berhubungan dengan penurunan kadar hemoglobin secara signifikan (95% CI: 11–11.8; p<0,001). Kesimpulannya, pola makan tinggi protein hewani dan nabati berhubungan positif dengan peningkatan kadar hemoglobin pada ibu hamil. Temuan ini menekankan pentingnya intervensi gizi berbasis protein dalam pencegahan anemia

selama kehamilan.
Kata Kunci: Analisis komponen utama, anemia, pola makan, kadar hemoglobin, ibu hamil

Introduction

Anemia in pregnancy is a condition characterized by decreased hemoglobin levels, which reduces the blood's ability to deliver oxygen to both the mother and fetus (Diana et al., 2019). During pregnancy, physiological changes, such as increased plasma volume, can lead to lower hemoglobin concentrations, making pregnant women more susceptible to anemia, especially around 20–24 weeks of gestation (Das et al., 2023).

Anemia during pregnancy is a global health issue that affects the health of mothers and newborns in both developing and developed countries (Zulfiqar et al., 2021). According to the World Health Organization (WHO), anemia during pregnancy affects approximately 38% of the global population (Shah et al., 2022). The prevalence of anemia during pregnancy in developed countries, such as Australia, is approximately 25%, while in developing regions, such as Africa, it is approximately 46.3%, and in Southeast Asia, it is approximately 48.7% (Bar-Zeev et al., 2014).

The prevalence of anemia among pregnant women in Indonesia remains high and has shown an increasing trend, rising from 37.1% in 2013 to 48.9% in 2018 (Kementerian Kesehatan Republik Indonesia, 2018). More recent data from the 2023 Indonesian National Health Survey (SKI) reported that 27.7% of pregnant women in Indonesia were anemic, indicating that anemia continues to be a major public health concern.

A fetus whose mother experiences anemia during the first trimester is at risk of being small for gestational age (SGA); during the second trimester, there is a risk of macrosomia; and in the third trimester, anemia may have long-term effects on neurocognitive development during childhood. For the mother, anemia during pregnancy increases the risk of preeclampsia, cardiac decompensation, and infectious shock during the intrapartum and postpartum periods, as well as postpartum hemorrhage (Stephen et al., 2018). Since maternal nutritional status is essensial for preventing anemia and ensuring healthy pregnancy outcome (Salatas et al., 2025)

The condition of pregnant women with anemia can be influenced by both direct and indirect factors. Direct factors affecting hemoglobin levels in pregnant women include dietary patterns, bleeding, nutritional status, infection, and iron tablet consumption. Indirect factors include parity, maternal age, birth spacing, social status, economic status, and education (Purwaningtyas & Prameswari, 2024).

Globally, the main cause of anemia during pregnancy is iron deficiency, which accounts for approximately 56% of cases. In addition, 36% of cases are due to micronutrient deficiencies (such as Vitamin A, B6, B12, riboflavin, zinc, and folic acid), and the remaining 8% are caused by hereditary disorders such as thalassemia (Das et al., 2023). In developing countries, iron deficiency is primarily related to inadequate nutritional intake (Mayasari et al., 2023).

Dietary patterns play a crucial role in determining hemoglobin levels and overall nutritional status. Unlike single-nutrient analysis, dietary pattern analysis provides a more comprehensive understanding of food consumption behavior by capturing the cumulative and interactive effects among various food groups (Syauqy et al., 2018). Previous studies have concluded that dietary pattern analysis considers the cumulative and interactive effects among dietary food groups, reflecting the complexity of human eating behavior (Zhao et al., 2021). In addition to the overall dietary pattern, other protective factors against anemia include iron-folic acid supplementation and higher educational attainment, which contribute to improved maternal nutritional status and pregnancy outcomes (Chillo et al., 2025).

During pregnancy, nutritional requirements increase significantly, making appropriate dietary patterns essential for preventing anemia. A study conducted in Jordan found that dietary diversity, characterized by the consumption of various healthy food groups, was positively associated with higher hemoglobin and ferritin levels (Al-Bayyari et al., 2024). A study conducted in Taiwan on pregnant women showed that a diet high in vegetables, fruits, legumes, seeds, soy products, and whole grain cereals was associated with micronutrient status, such as iron, folate, and vitamin B12, which are essential components in red blood cell formation (Mayasari et al., 2023).

Iron from food is divided into two forms: heme iron (Fe^{2+}), derived from animal-based foods, and non-heme iron (Fe^{3+}), derived from plant-based foods. Fe^{2+} is directly absorbed into intestinal cells via the heme carrier protein 1 (HCP1) receptor, whereas Fe^{3+} is first reduced by the enzyme duodenal cytochrome B (DcytB) to Fe^{2+}, which is then absorbed by intestinal cells through the divalent metal transporter 1 (Correnti et al., 2024). Once in the bloodstream, Fe^{2+} is oxidized to Fe^{3+} and binds to transferrin for transport to the bone marrow. In the bone marrow, iron is released from transferrin and enters the mitochondria, where it combines with protoporphyrin III to form a haem molecule. Heme then binds to globin to form hemoglobin, which carries oxygen in red blood cells (Gupta, 2014).

This study aimed to explore the relationship between dietary patterns and hemoglobin levels in pregnant women. However, evidence on this association remains limited in Indonesia, particularly in North Sumatera, where dietary diversity and anemia prevalence vary by region. Understanding this relationship is expected to provide a scientific basis for developing context-specific nutritional interventions and informing maternal health policies aimed at preventing anemia during pregnancy.

Methods

This cross-sectional study was conducted at three community health centers in Asahan Regency, North Sumatra Province: Mutiara Health Center, Binjai Serbangan Health Center, and Silau Laut Health Center. Participant selection was conducted using a non-probability purposive sampling method to recruit pregnant women who met the predefined inclusion criteria. We acknowledge that this approach may limit the generalizability of the study results. The sample size was determined using the formula by Lwanga and Lemeshow, considering a 95% confidence level (Z=1.96), an expected prevalence of 30.3%, a margin of error, and a total population of 252. An additional 10% was added to account for potential dropouts, resulting in a final sample size of 170.

The inclusion criteria were pregnant women who could speak well and fluently and were willing to participate as respondents by signing the informed consent form. The exclusion criteria included pregnant women with tuberculosis, malaria, HIV, and blood disorders. Dietary pattern assessment: Trained nutritionists collected dietary data using food frequency questionnaires (FFQs). The FFQs, which were previously validated and modified for the North Sumatera population, contained 25 food items that represent typical local food patterns. Participants were asked how often they consumed each food item, and the scores of food intake were defined as 1–5, from the lowest to the highest frequency. The frequency scores were used to obtain dietary patterns, which were classified into tertiles. Hemoglobin levels were obtained through venous blood sampling performed by qualified laboratory personnel and analyzed using a Hematology Analyzer.

Demographic, anthropometric, and lifestyle information, including age, gestational age, education, parity, income, nutritional status, and sleep quality, were collected using a self-administered questionnaire. Upper arm circumference was measured using a measuring tape to assess the nutritional status of pregnant women. Income levels were categorized based on the Regional Minimum Wage (UMR): ≥UMR dan < UMR. The level of education was categorized as basic (below senior high school, equivalent to <9 school years) and high (senior high school and above, equivalent to ≥9 school years). Sleep quality scores were obtained using the Pittsburgh Sleep Quality Index (PSQI).

Dietary patterns were extracted using Principal Component Analysis (PCA), with components retained based on eigenvalues greater than 1.5 to enhance interpretability, and an orthogonal (varimax) rotation was subsequently applied. A higher eigenvalue threshold (>1.5) was used to retain only components that explained a substantial proportion of the total variance, thereby improving the interpretability and stability of the extracted dietary pattern (Teixeira et al., 2020). Factor loadings of ≥0.4 were considered to classify dietary patterns, as this threshold is commonly used to indicate a meaningful correlation between food items and identified factors (Field, 2024). Factor scores for each dietary pattern were derived by multiplying the intake of individual food groups by their respective factor loadings and summing the results for every participant. These scores were subsequently divided into tertiles to facilitate comparisons across adherence levels. Dietary pattern labels were assigned based on food groups with the most prominent factor loadings. To analyze the differences in demographic, anthropometric, and lifestyle variables across tertiles of dietary patterns, we used the chi-square test for categorical variables and Kruscall-Wallis test for continuous variables. Analysis of covariance was performed to examine the relationship between dietary patterns and hemoglobin levels. The mean value (95% CI) of hemoglobin levels was calculated for participants with different dietary patterns after adjusting for demographic, anthropometric, and lifestyle factors. Prior to the analysis, the assumptions of ANCOVA, including normality, homogeneity of variance, and homogeneity of regression slopes, were verified.

Multivariate linear regression was conducted to explore the relationship between dietary patterns and hemoglobin levels after adjusting for multiple confounding variables using two models. Model 1 was adjusted for demographic data (age, gestational age, parity, education, and income). Model 2 additionally included anthropometric and lifestyle variables (mid-upper arm circumference and sleep quality). Prior to the analysis, the assumptions of linear regression, including linearity, normality, and multicollinearity among predictors, were tested, and no multicollinearity was detected (VIF<10). Statistical significance was set at $p < 0.05$. All statistical analyses were performed using SPSS version 25.

Ethical clearance was obtained from the Ethics Committee of Diponegoro University (number 051/EC/KEPK/FK-UNDIP/III/2025). All respondents were informed of the study's objectives, procedures, and benefits before participation. Informed consent was obtained from all participants before data collection. Confidentiality and anonymity were guaranteed, and participants were informed that they had the right to withdraw from the study at any time without penalty.

Result and Discussion

Table 1 presents the respondents' characteristics. The median age of 28 years indicatese that most respondents were within the active reproductive period, a stage generally associated with optimal fertility and favorable pregnancy outcomes. The median parity was 2, suggesting that a considerable proportion of participants had previous pregnancy experience, which may have influenced their nutritional and health-related behaviors. Most participants had attained at least a senior high school education, and over half reported an income above the regional minimum wage. These finding reflect relatively favorable socioeconomic conditions that could facilitate better access to health service and support adequate nutritional intake during preganancy.

The mean mid-upper arm circumference (MUAC) was 26.4 cm, reflecting an overall good nutritional status among respondents. However, the wide range (18.3-36.2) indicatesthatthat women in the underweight BMI category may still be at risk of undernutrition, warranting closer nutritional monitoring. The median hemoglobin concentration of 11.4 g/dL was within the normal range, indicating that the prevalence of anemia was likely low in this population, although continued screening remains essential to prevent adverse maternal outcomes. The median sleep quality score of 5 points indicates mild to moderate sleep disturbances, which may affect maternal well-being and should be addressed through appropriate prenatal care.

Tabel 1. Characteristics of all the subjects (n=170)

Characteristics	All Subject
Age (years)	28 (14-42)
Parity (n)	2 (1-5)
Gestational Age (weeks)	23 (1-38)
Educatiom (%)	
Higher	65.9
Basic	34.1
Income (%)	
≥ RMW	51.8
< RMW	48.2
MUAC (cm)	26.4 (18.3-36.2)
Sleep quality (score)	5 (2-14)
Hemoglobin (g/dL)	11.4 (10.1-14.9)

MUAC: mid-upper arm circumference; RMW: regional minimum wage; values are presented as median (min-max) for continuous variables or % for categorical variables.

Table 2 presents the four major dietary patterns identified through PCA, which together explained 53.7% of the total variance (factor 1:28.87%, factor 2:10.41%, factor 3:7.99%, factor 4:6.41%, all with eigenvalues >1.5). The first factor, representing an animal- and plant-based protein dietary pattern, accounted for the largest variance, indicating that protein-rich foods such as meat, soy, poultry, eggs, and animal organs were central to the dietary habits of pregnant women in North Sumatera. This suggests a balanced preference for both animal and plant protein sources. The subsequent patterns reflected a combination of vegetable-based foods, high-fat and sweet items, and dairy or processed foods, highlighting the diversity of dietary intake in this population. Overall, these loading patterns illustrate how traditional and modern food choices coexist within local maternal diets.

Table 2. Factor loadings of four dietary patterns identified by principal component analysis

Food Group	Animal and Plant-Based Protein Dietary Pattern	Light and Dark-Colored Vegetable Dietary Pattern	High Fat and Sweet Dietary Pattern	Dairy and Processed Food Dietary Pattern
Rice/Flour-Based Products	-0.410	0.133	0.181	-0.018
Staple Foods Cooked with Oil	-0.092	-0.243	0.521	0.018
Root Vegetables	-0.166	0.136	0.535	-0.275
Whole Grains	-0.011	0.457	0.146	-0.086
Legumes	0.401	0.730	-0.240	-0.102
Soy-Based Products	0.752	0.368	-0.269	0.070
Dairy and Dairy-Based Products	0.057	-0.143	0.028	0.672
Light-Colored Vegetables	-0.037	0.840	-0.206	-0.032
Dark-Colored Vegetables	0.238	0.794	-0.375	0.155
Eggs	0.543	0.542	-0.250	-0.201
Fish and Seafood	0.496	0.770	-0.157	0.078
Red Meat	0.809	0.175	-0.016	0.042
Poultry	0.618	0.373	0.236	0.074
Fast Food	-0.842	-0.016	0.218	0.043
Processed Foods	-0.695	-0.129	0.053	0.463
Fried Foods	-0.111	-0.140	0.581	-0.191
Animal Organs	0.465	0.170	-0.253	0.298
Fruits	-0.083	-0.014	0.113	0.039
Processed Fruits	0.091	-0.236	0.610	0.385
Traditional Snacks	0.030	0.278	0.677	0.199
Jam/Honey	-0.035	0.116	0.033	0.648
Sugary Drinks	-0.210	-0.108	0.739	0.163
Sweet Desserts	-0.177	-0.109	0.696	-0.057
Tea and Coffee	-0.652	-0.227	0.232	-0.180
Traditional Beverage	0.205	0.286	0.092	0.181

After the dietary patterns were identified through PCA, further analysis was conducted to examine the characteristics of respondents across tertiles of these dietary patterns, beginning with the high animal-and plant-based protein dietary pattern.

The characteristics of respondents based on tertiles of the High Animal and Plant-Based Protein dietary pattern showed no significant differences in age, parity, education level, income, or mid-upper arm circumference (MUAC) across tertiles (all p>0.05). However, significant differences were found in gestational age (p=0.011), sleep quality (p=0.002), and hemoglobin levels (p<0.001). The highest median gestational age and poorest sleep quality were both observed at T1 (28 weeks; score: 6). Hemoglobin levels increased consistently from

T1 to T3 (11.2, 11.7, and 12.3 g/dL), indicating a positive relationship with this dietary pattern.

The characteristics of respondents based on tertiles of the Bright and Dark Colored Vegetable dietary patterns showed no significant differences in age, parity, education, income, or MUAC (p>0.05). Significant differences were found in gestational age (p<0.001), sleep quality (p=0.002), and hemoglobin level (p=0.015). The highest median gestational age was in T2 (28 weeks), and the best sleep quality (lowest score) was observed in T3. Hemoglobin levels were highest in T3 (11.8 g/dL) and lowest in T1 (11.5 g/dL), indicating a possible contribution of vegetable intake to hemoglobin status.

The characteristics of respondents based on tertiles of the high-fat and sweet dietary pattern showed no significant differences in most variables, including age, parity, gestational age, income, sleep quality, and MUAC (p>0.05). However, a significant difference was found in the education level (p=0.015), with the highest proportion of higher education in T3 (41.1%). Hemoglobin levels also varied significantly (p=0.006), with the highest median in T2 (11.9 g/dL) and the lowest in T3 (11.3 g/dL), suggesting a negative association between high fat and sugar intake and hemoglobin levels.

The characteristics of respondents based on tertiles of the Dairy And Processed Food Dietary Pattern showed no significant differences in age, parity, education, income, or MUAC (all p>0.05). However, gestational age (p=0.008) and sleep quality (p=0.040) differed significantly. The highest median gestational age was observed in T3 (26 weeks), whereas the poorest sleep quality was observed in T1 (median score: 6). Although the difference in hemoglobin levels was not statistically significant (p=0.068), the highest median hemoglobin was found in T2 (11.8 g/dL), and the association between dairy intake and hemoglobin levels was not statistically significant.

The high-protein dietary pattern, particularly one combining both animal- and plant-based sources, was associated with higher hemoglobin levels. Hemoglobin concentrations consistently increased across the dietary tertiles. The consistent rise in hemoglobin levels across dietary tertiles strengthens the evidence that animal-based protein, as a source of highly bioavailable heme iron, plays a crucial role in anemia prevention, whereas plant-based protein is essential in complementing the requirements for essential amino acids. These findings highlight the importance of balanced dietary interventions during pregnancy to support maternal health and optimize fetal growth (Fera et al., 2021).

Similarly, dietary patterns characterized by bright and dark-colored vegetables were significantly associated with key maternal health indicators, particularly gestational age, sleep quality, and hemoglobin levels. The absence of significant differences in age, parity, education, income, and MUAC (p>0.05) suggests that sociodemographic factors and baseline nutritional status were relatively homogeneous across tertiles. Therefore, the observed clinical variations are likely attributable to differences in vegetable intake. The significant difference in gestational age (p<0.001) may be explained by variations in physiological and metabolic demands during pregnancy, where the consumption of micronutrient-rich vegetables may support fetal development while maintaining maternal health. The improved sleep quality in T3 is consistent with previous studies reporting that vegetable intake, particularly those rich in magnesium, vitamin C, and antioxidants, contributes to melatonin regulation and the reduction of oxidative stress, thereby positively influencing maternal sleep patterns. Furthermore, the higher hemoglobin levels in T3 (11.9 g/dL) than in T2 (11.2 g/dL) strengthen the hypothesis that the consumption of colored vegetables, especially dark green vegetables rich in non-heme iron and folate, contributes to hematological status. This mechanism may also be supported by the vitamin C content of brightly colored vegetables, which enhances the absorption of non-heme iron in the gastrointestinal tract. These findings highlight the importance of a diverse diet rich in vegetables for preventing anemia during pregnancy (Abioye et al., 2021).

In contrast, the high-fat and sweet dietary patterns appeared to have an adverse effect on the maternal hematological status. Despite a significant variation in education level (p=0.015), with the highest proportion of respondents attaining higher education in T3, educational attainment does not necessarily translate into healthier food choices. This aligns with previous studies reporting that even individuals with higher education may adopt dietary habits high in fats and refined sugars due to lifestyle preferences, convenience, or processed food exposure.

Furthermore, the observed decrease in hemoglobin levels across tertiles, with the lowest median in T3 (11.3 g/dL), provides evidence of a potential negative association between excessive fat and sugar consumption and hemoglobin concentration. A high intake of refined carbohydrates and saturated fats has been reported to impair iron absorption and utilization, partly through increased inflammation, oxidative stress, and competition with other macronutrients. Moreover, sugar-rich diets may displace nutrient-dense foods, leading to insufficient intake of iron, folate, and other hematopoietic micronutrients (Hayashi et al., 2023).

Meanwhile, milk and dairy product consumption showed different associations, being linked with several aspects of maternal health, although not all differences were statistically significant. The significant differences observed in gestational age and sleep quality may reflect specific consumption patterns at different stages of pregnancy, as well as the potential influence of milk nutrients, such as protein and tryptophan, on sleep regulation. Although the findings on hemoglobin levels were not statistically significant, they revealed an interesting trend, with the highest median observed in T2, which may indicate a possible role of milk in supporting iron status or maternal hematological health (Purnamasari et al., 2022).

Table 3. Multiple linier regresion analysis of the association between dietary pattern and hemoglobin

Hemoglobin (g/dL)	T1 (Ref)	T2	T3	p-value
Animal and Plant-Based Protein Dietary Pattern				
Model 1	11.02 (10.63-11.41)	11.75 (11.34-12 .15)	12.39 (12.03-12.75)	0.000
Model 2	11.05 (10.65-11.45)	11.75 (11.34-12.15)	12.38 (12.02-12.75)	0.000
Light and Dark-Colored Vegetable Dietary Pattern				
Model 1	11.50 (11.14-11.86)	11.77 (11.39-12.16)	11.89 (11.50-12.28)	0.054
Model 2	11.51 (11.15-11.88)	11.80 (11.40-12.19)	11.87 (11.47-12.27)	0.231
High Fat and Sweet Dietary Pattern				
Model 1	11.80 (11.45-12.15)	11.96 (11.57-12.35)	11.39 (11-11.79)	0.001
Model 2	11.80 (11.45-12.15)	11.97 (11.58-12.37)	11.41 (11-11.81)	0.001
Dairy and Processed Food Dietary Pattern				
Model 1	11.72 (11.33-12.11)	11.81 (11.44-12.17)	11.63 (11.26-12)	0.099
Model 2	11.75 (11.35-12.15)	11.80 (11.43-12.16)	11.63 (11.26-12)	0.274

Values are expressed as mean (95% CI). Model 1 was adjusted for age, parity, gestational age, education level, and income. Model 2 was adjusted for age, parity, gestational age, education, income, nutritional status and sleep quality.

Table 3. explored the multivariable-adjusted means of hemoglobin levels across tertiles of dietary patterns. The animal- and plant-based protein dietary patterns showed a positive linear association with hemoglobin levels, as Hb levels increased progressively from the lowest to the highest tertile after adjustment for both Model 1 (age, parity, gestational age, education, and income) and Model 2 (Model 1 plus nutritional status and sleep quality) (alpes < 0.05). In contrast, higher consumption of the High Fat and Sweet Dietary Pattern was negatively associated with hemoglobin levels after adjustment for both Models 1 and 2 (all adjusted $p < 0.05$). Consumption of the light- and dark-colored vegetable dietary patterns showed no significant association with hemoglobin levels after adjustment for Model 1 (adjusted for age, parity, gestational age, education, and income) and Model 2 (Model 1 plus nutritional

status and sleep quality) (all adjusted p-values > 0.05). Similarly, the consumption of dairy and processed food dietary patterns showed no significant association with hemoglobin levels in either model (all adjusted p > 0.05).

This study identified four dietary patterns: animal- and plant-based protein, light- and dark-colored vegetables, high-fat and sweet foods, and dairy and processed foods. Dietary patterns provide a more comprehensive representation of nutrient intake among pregnant women than individual food items and nutrients (Zhao et al., 2021). Compared to other patterns, the protein-based dietary pattern accounted for the largest share of the total variance, reflecting a predominant dietary habit centered on nutrient-dense foods such as fish, eggs, tofu, and tempeh. This suggests that local food culture continues to influence the eating behaviors of pregnant women, supporting protein rich choices that may help improve maternal nutritional status.

The findings revealed that a dietary pattern high in animal- and plant-based protein was significantly associated with increased hemoglobin levels. Compared with other dietary patterns, this protein-based pattern consistently showed a positive association with hemoglobin levels across both Models 1 and 2. This suggests that a balanced combination of proteins from both animal and plant sources plays a crucial role in supporting hemoglobin synthesis. Animal- and plant-based protein dietary patterns are characterized by high protein content and essential micronutrients, including iron, vitamin B12, folate, zinc, and vitamin A, all of which are positively associated with hemoglobin levels (Ronkainen et al., 2022). Approximately 80% of the body's iron is involved in hemoglobin production in red blood cells (Vogt et al., 2021), making iron deficiency the most common cause of anemia in the world. Consistent with this study, research in Aceh found that pregnant women with adequate intake of animal- and plant-based protein had normal Hb levels (Fera et al., 2021). This aligns with findings from Ghana, where such a dietary pattern contributed to higher Hb levels, indicating that including both sources of protein helps improve iron stores(Callister & Aguilar-Alvarez, 2021). Similarly, a study in Taiwan reported that a low-plant and high-animal protein diet was linked to lower hemoglobin levels, whereas a high-plant, low-animal diet was associated with moderate-to-severe anemia (Purnamasari et al., 2022).

The light- and dark-colored vegetable dietary pattern, which includes sources of non-heme iron, initially showed a significant association with Hb levels. However, this relationship became non-significant after adjusting for age, gestational age, parity, income, education, nutritional status, and sleep quality, which may act as confounders that independently affect hemoglobin concentration. Although vegetables are e important sources of t micronutrients, the bioavailability of non-heme iron remains low (approximately 5–1 because of antinutrients sucas phytatet and noxalatewhichat form insoluble complexes with iron and inhibit its absorption. Vitamin C serves as a key enhancer, reducing Fe^{3+} to Fe^{2+}, which is more easily absorbed by enterocytes (Sulaiman et al., 2021).

The high-fat and sweet dietary patterns demonstrated a significant negative association with Hb levels, which persisted after multivariable adjustments. The pattern showed a non-linear trend, suggesting that moderate consumption may be less detrimental than excessive intake. From a pathophysiological perspective, excessive consumption of sugary and fatty foods may trigger systemic inflammation and oxidative stress, activating the hepcidin pathway and reducing the expression of iron transporters, such as ferroportin. Elevated hepcidin impairs intestinal iron absorption and its distribution to active erythropoiesis (Zaugg et al., 2024). Consistently, a study from Japan reported that high consumption of sugary foods was associated with insulin resistance and visceral fat accumulation, resulting in a higher Dietary Inflammatory Index score that was significantly related to lower maternal Hb levels during the third trimester, particularly among women with gestational diabetes mellitus (Zaugg et al., 2024).

The dairy and processed food dietary patterns showed a slight, non-significant association with hemoglobin levels after adjustment. Although dairy products provide protein and energy, their calcium content may inhibit non-heme iron absorption through competitive interactions in the small intestinal mucosa (Abioye et al., 2021). Calcium consumption alongside iron sources can reduce iron bioavailability, ultimately limiting hemoglobin improvement despite increased energy intake (Morales Suárez-Varela et al., 2023). In addition, processed foods are generally high in sodium, saturated fat, and additives but low in essential micronutrients, such as iron and vitamin C. A diet with a high proportion of ultra-processed foods has also been linked to increased systemic inflammation, which can stimulate hepcidin production, reducing iron absorption and utilization. Recent evidence supports this mechanism, showing that freuqent of UPF consumption decrease dietary iron availability and increases anemia risk (Queiroz et al., 2025)

This Study had several strengths, including a large and representative sample size and the application of a posteriori methods to identify dietary patterns that accurately reflect actual eating behaviors within the study population. Nevertheless, several limitations of this study should be acknowledged. First, the use of a a posteriori dietary pattern analysis may reduce reproducibility, as principal component analysis involves subjective decisions regarding factor retention and rotation methods. Consequently, the identified patterns may be population-specific and have limited generalizability to other settings. Second, hemoglobin concentration was the sole biomarker used to assess anemia status, which restricts the accuracy of the diagnosis. A more comprehensive evaluation would require additional biochemical indicators, such as ferritin, serum ions, and C-reactive protein (CRP), to account for iron status and inflammation. Finally, the cross-sectional design precludes causal inference between dietary patterns and hemoglobin levels, limiting the interpretation of temporal relationships.

Despite these limitations, this study provides valuable insights into public health nutrition. The findings indicate that promoting dietary patterns rich in both animal- and plant-based protein sources could be an effective strategy to enhance hemoglobin levels among pregnant women. Healthcare professionals should consider developing targeted nutrition education and intervention programs that emphasize adequate protein intake and the reduction of high-sugar and high-fat foods. Further longitudinal or interventional studies are warranted to confirm these associations and inform evidence-based dietary recommendations for improving maternal health.

Conclusion

This study found that the animal- and plant-based protein dietary patterns were significantly associated with higher hemoglobin levels among pregnant women, even after adjusting for relevant covariates. In contrast, the high-fat and sweet dietary patterns showed a non-linear association, with hemoglobin levels declining in the highest tertile, suggesting possible adverse effects of excessive intake. Meanwhile, the light- and dark-colored dietary patterns and the dairy and processed food patterns did not show significant associations with hemoglobin levels after adjustments.

A balanced diet rich in both animal- and plant-based proteins plays a greater role in improving hemoglobin levels during pregnancy. These findings highlight the need to promote balanced protein-based dietary habits as part of nutritional interventions for the prevention of anemia in pregnant women. Future research with longitudinal or interventional designs is recommended to confirm these associations and strengthen the causal inference.

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