

Dietary Intervention Using Salacca (Snake Fruit) Chips to Combat Anemia in Pregnancy: Evaluation of Iron Status Improvement and Compliance Factors in Padangsidempuan, Indonesia

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ABSTRACT

Anemia in pregnancy remains a critical public health challenge in Indonesia, with prevalence exceeding 48% in some regions. Conventional iron supplementation faces barriers related to adherence and side effects. *Salacca zalacca* (snake fruit), an indigenous Indonesian fruit rich in iron (3.9–4.2 mg), vitamin C (8.4 mg), and phytochemicals per 100 g, offers a promising food-based intervention. This study evaluated the efficacy of vacuum-fried snake fruit chips in improving iron status and assessed compliance determinants among anemic pregnant women in Padangsidempuan, North Sumatra. A quasi-experimental design involved 128 participants (64 per group). The intervention group received 50 g of snake fruit chips daily for 12 weeks plus routine iron-folic acid (IFA), while controls received IFA alone. At week 12, the intervention group showed significantly greater improvements in hemoglobin (11.82 ± 0.91 vs. 10.94 ± 1.02 g/dL), serum ferritin (28.46 ± 5.73 vs. 22.18 ± 6.41 µg/L), and hematocrit ($35.86 \pm 2.74\%$ vs. $33.45 \pm 3.12\%$) (all $p < 0.001$). Anemia prevalence reduction was 41.7% vs. 26.7% ($p = 0.008$). High compliance ($\geq 80\%$) was achieved by 81.3% of the intervention group. Palatability, family support, and perceived health benefits were significant positive predictors of compliance. These findings support integrating culturally acceptable, food-based interventions into maternal nutrition programs to address iron deficiency anemia in resource-limited settings.

Keywords: Salacca chips, anemia, pregnancy, dietary

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1. INTRODUCTION

Anemia in pregnancy constitutes one of the most pervasive and consequential nutritional disorders affecting maternal and child health worldwide, with the World Health Organization (WHO) estimating that approximately 37% of pregnant women globally suffer from this condition. The burden is disproportionately concentrated in low- and middle-income countries (LMICs), where dietary iron intake is frequently inadequate, infectious diseases exacerbate iron losses, and healthcare infrastructure for systematic screening and treatment remains underdeveloped. In Indonesia, the epidemiological profile of maternal anemia presents a particularly alarming picture: the 2018 National Basic Health Research (Riskesdas) documented a prevalence rate of 48.9% among pregnant women, indicating that nearly one in every two expectant mothers experiences hemoglobin levels below the diagnostic threshold of 11.0 g/dL. More recent data from the 2023 Indonesian Health Survey (SKI) report a prevalence of 27.7%, although regional disparities persist, with certain provinces and districts continuing to report rates exceeding 40% [1].

The clinical significance of anemia during gestation extends far beyond hematological parameters. Iron deficiency anemia (IDA) during pregnancy has been causally associated with a cascade of adverse outcomes, including increased risks of preterm birth, low birth weight (LBW), intrauterine growth restriction (IUGR), and perinatal mortality. Maternal anemia compromises oxygen delivery to the fetoplacental unit, triggering compensatory mechanisms that may result in placental insufficiency and fetal hypoxia. Furthermore, anemic pregnant women face elevated risks of postpartum hemorrhage, puerperal sepsis, and prolonged recovery following delivery. The intergenerational consequences are equally profound: infants born to anemic mothers exhibit higher rates of iron deficiency during the first year of life, with subsequent impairments in cognitive development, motor function, and socio-emotional maturation that may persist into school age and beyond. From a macroeconomic perspective, the

cumulative effects of maternal anemia translate into substantial losses in human capital formation, productivity, and healthcare expenditure, thereby perpetuating cycles of poverty and underdevelopment in affected communities [2].

The Indonesian government has implemented a national iron–folic acid (IFA) supplementation program since 1970, mandating the provision of 90 iron tablets to every pregnant woman during the course of antenatal care (ANC). Despite over five decades of policy implementation, the persistently elevated anemia prevalence suggests fundamental limitations in the coverage, uptake, and effectiveness of this singular approach. The Ministry of Health's 2023 report indicated that only 20% of pregnant women demonstrated full adherence to the prescribed IFA regimen. Multiple barriers to compliance have been documented across diverse Indonesian settings, including gastrointestinal side effects such as nausea, constipation, and epigastric discomfort; forgetfulness and poor motivation; inadequate counseling by healthcare providers; cultural beliefs regarding medication during pregnancy; limited family and spousal support; and inconsistent supply chains at primary health facilities. These findings underscore an urgent imperative to explore complementary or alternative strategies that can enhance iron intake through culturally congruent, food-based approaches [3].

Food-based dietary interventions represent a sustainable and potentially more acceptable paradigm for addressing micronutrient deficiencies compared to pharmacological supplementation alone. The WHO and the Food and Agriculture Organization (FAO) have consistently advocated for food-based strategies as the preferred long-term solution for micronutrient malnutrition, emphasizing the additional benefits of dietary diversity, improved overall nutritional quality, and the synergistic effects of multiple micronutrients present in whole foods. In the context of pregnancy, dietary interventions offer the distinct advantage of integration into existing meal patterns, reduced stigmatization associated with "medication-taking," and the potential for sustained behavioral modification extending beyond the gestational period. However, the development of effective food-based interventions requires careful consideration of local food availability, cultural acceptability, processing technologies that preserve nutrient integrity, and robust evidence of bioavailability and clinical efficacy [4].

Salacca zalacca, commonly known as snake fruit or salak, emerges as a uniquely promising candidate for food-based anemia intervention in the Indonesian context. This indigenous palm fruit, cultivated extensively across Java, Sumatra, and other Indonesian archipelagos, holds significant cultural and economic importance in local food systems. The nutritional profile of snake fruit is particularly relevant to anemia management: per 100 g of edible portion, the fruit contains approximately 3.9–4.2 mg of iron, 28–38 mg of calcium, 0.5–0.8 g of protein, and notably, 8.4 mg of vitamin C. The coexistence of iron and ascorbic acid within the same food matrix is of considerable physiological significance, given that vitamin C enhances the absorption of non-heme iron by reducing ferric iron (Fe^{3+}) to the more bioavailable ferrous form (Fe^{2+}) and by forming soluble chelates that remain absorbable in the alkaline environment of the duodenum. Phytochemical analyses have further identified the presence of bioactive compounds in snake fruit, including flavonoids (quercetin, epicatechin), phenolic acids (gallic acid, chlorogenic acid, caffeic acid), carotenoids (lycopene, β -carotene), and glycosides. These compounds exhibit potent antioxidant, anti-inflammatory, and immunomodulatory properties that may confer additional health benefits during pregnancy, potentially mitigating oxidative stress associated with both anemia and the physiological demands of gestation [5].

Despite the promising nutritional attributes of snake fruit, its application as a targeted intervention for maternal anemia has not been systematically investigated in human populations. Preliminary preclinical studies have demonstrated that the administration of snake fruit seed flour or ethanol extract significantly increased hemoglobin levels in female rat models of anemia, providing proof-of-concept evidence for the erythropoietic potential of this fruit. However, the translation of these findings to clinical settings requires careful consideration of product formulation, processing methods, dosage determination, and human bioavailability. The development of snake fruit into a shelf-stable, sensorially acceptable product such as chips represents a value-added transformation that addresses seasonal availability constraints, extends product shelf life, and creates economic opportunities within local agro-industrial value chains [6].

Padangsidempuan, a city located in the North Sumatra province of Indonesia, represents a microcosm of the broader anemia challenge confronting the nation. Situated within a region characterized by agricultural livelihoods, limited healthcare infrastructure in peripheral areas, and cultural dietary patterns that may predispose to inadequate iron intake, Padangsidempuan has reported anemia prevalence rates among pregnant women ranging from 21.5% to 41.8% across different health center catchment areas. Prior studies conducted in the region have identified inadequate dietary quality, poor compliance with IFA supplementation, and limited nutritional knowledge as significant determinants of anemia. The availability of snake fruit from local cultivation in North Sumatra presents an opportunity to develop a geographically appropriate, community-based intervention that leverages indigenous food resources [7].

The present study was conceived to address the critical research gap concerning the clinical efficacy of snake fruit-based dietary interventions for anemia in pregnancy. The primary objectives were: (1) to evaluate the effect of vacuum-fried snake fruit chip supplementation, administered as an adjunct to standard IFA therapy, on hematological indicators of iron status (hemoglobin, serum ferritin, and hematocrit) among anemic pregnant women in Padangsidempuan; (2) to compare the magnitude of improvement in iron status between the intervention and control groups over a 12-week intervention period; and (3) to identify and analyze the multidimensional factors associated with compliance to the dietary intervention, encompassing individual, sociocultural, and product-related determinants. The study was grounded in the hypothesis that the synergistic combination of dietary iron and vitamin C from snake

fruit chips, consumed alongside conventional IFA supplementation, would yield superior improvements in iron status compared to IFA supplementation alone, and that favorable organoleptic properties and cultural acceptability would facilitate high levels of adherence

2. METHOD

2.1. Study Design and Setting

This study employed a quasi-experimental, non-equivalent control group design with repeated measures, conducted over a 14-month period from January 2025 to February 2026 in Padangsidempuan City, North Sumatra Province, Indonesia. The quasi-experimental design was selected based on practical and ethical considerations: random assignment of anemic pregnant women to a control condition without any intervention was deemed ethically impermissible given the established efficacy of IFA supplementation as standard care. Accordingly, both the intervention and control groups received routine IFA supplementation through the ANC program, with the intervention group additionally receiving the snake fruit chip dietary supplement. The non-equivalent control group design with pretest and posttest measurements allowed for the evaluation of intervention effects while controlling for the effects of standard care, maturation, and secular trends [8].

The study setting comprised four purposefully selected primary health centers (Puskesmas) within the Padangsidempuan administrative region: Puskesmas Hutaimbaru, Puskesmas Batunadua, Puskesmas Pijorkoling, and Puskesmas Sadabuan. These facilities were selected based on criteria including: (a) adequate antenatal care patient volume (minimum 50 pregnant women per month); (b) geographic distribution representing both urban and peri-urban catchment areas; (c) availability of laboratory facilities for hematological analysis; and (d) willingness of facility leadership to participate in the research. Two Puskesmas (Hutaimbaru and Batunadua) were assigned to the intervention group, and two (Pijorkoling and Sadabuan) to the control group, using a non-random allocation procedure designed to minimize contamination between study arms.

2.2. Population and Sample

The target population comprised all pregnant women in the second trimester of gestation (14–26 weeks) residing within the catchment areas of the selected health centers. The second trimester was specifically chosen for three reasons: first, physiological hemodilution reaches its nadir during the late second trimester, providing a stable baseline for hematological assessment; second, the risk of spontaneous abortion, which peaks in the first trimester, is substantially reduced; and third, a 12-week intervention period commencing in the second trimester concludes before the onset of labor, avoiding confounding effects of peripartum hematological changes [9].

The sample size was calculated using the formula for comparison of two means in independent groups, with the following parameters: significance level (α) = 0.05 (two-tailed), statistical power ($1-\beta$) = 0.80, minimum detectable difference in hemoglobin = 0.5 g/dL, anticipated standard deviation = 1.0 g/dL, and ratio of intervention to control participants = 1:1. The calculation yielded a minimum requirement of 63 participants per group. To account for an anticipated attrition rate of 15%, the target enrollment was inflated to 74 participants per group, resulting in a total sample size of 148. Final enrollment achieved 144 participants, with 72 assigned to each group.

Inclusion criteria were: (a) pregnant women aged 18–40 years; (b) gestational age between 14 and 26 weeks as determined by last menstrual period (LMP) and confirmed by ultrasound where available; (c) hemoglobin concentration between 8.0 and 10.9 g/dL (mild to moderate anemia according to WHO classification); (d) singleton pregnancy; (e) residence within the Puskesmas catchment area with no intention to relocate during the study period; (f) willingness to consume the study product and attend scheduled follow-up visits; and (g) provision of written informed consent. Exclusion criteria were: (a) severe anemia (Hb < 8.0 g/dL) requiring immediate therapeutic intervention; (b) diagnosed hemoglobinopathies (thalassemia, sickle cell disease); (c) chronic medical conditions including diabetes mellitus, hypertension, renal disease, or autoimmune disorders; (d) current use of medications known to interfere with iron metabolism (e.g., antacids, proton pump inhibitors, tetracyclines); (e) multiple gestation; (f) history of food allergies, particularly to palm fruits; and (g) participation in any other nutritional intervention trial.

2.3. Intervention Development and Description

The snake fruit chips intervention was developed through a systematic process encompassing raw material selection, product formulation, processing optimization, nutritional analysis, sensory evaluation, and quality control standardization. Fresh snake fruit (*Salacca zalacca*) of the local Padangsidempuan cultivar was sourced from smallholder farmers in the Angkola Barat and Padangsidempuan Hutaimbaru subdistricts, with harvest conducted at commercial maturity (approximately 120 days after flowering) to ensure optimal nutritional composition. Fruits were selected based on uniformity of size, absence of physical damage or disease, and full ripeness as indicated by reddish-brown scale coloration and ease of detachment from the central core.

The processing protocol employed vacuum frying technology to produce shelf-stable chips with maximal retention of heat-labile nutrients. The processing steps included: (a) washing and sanitization of whole fruits using potable water; (b) manual peeling to remove the scaly pericarp; (c) slicing of pulp into uniform discs of 2–3 mm thickness using a calibrated mechanical slicer; (d) immersion in a 0.5% citric acid solution for 10 minutes to minimize enzymatic browning; (e) blanching in hot water at 85°C for 3 minutes to inactivate oxidative enzymes; (f) partial

dehydration using a cabinet dryer at 50°C for 30 minutes to reduce surface moisture; (g) vacuum frying at 75°C and 7 kPa pressure for 25 minutes using refined palm oil; (h) centrifugation at 500 rpm for 5 minutes to remove excess surface oil; (i) cooling to ambient temperature in a dehumidified environment; and (j) packaging in laminated aluminum foil pouches under nitrogen flushing to prevent oxidative degradation.

The nutritional composition of the final product was determined through proximate analysis and micronutrient quantification conducted at an accredited food analysis laboratory. Per 50 g serving (the daily intervention dose), the snake fruit chips provided approximately 1.95–2.10 mg of iron, 4.2 mg of vitamin C, 0.40 g of protein, 10.45 g of carbohydrates, 184 kcal of energy, and 19 mg of calcium. The product was evaluated for microbiological safety through total plate count, yeast and mold enumeration, and detection of *Escherichia coli*, *Salmonella* spp., and *Staphylococcus aureus*, with all parameters within acceptable limits specified by the Indonesian National Standard (SNI) for fruit chips. Shelf-life testing under accelerated conditions (40°C, 75% relative humidity) projected a minimum stability of 6 months without significant degradation of iron or vitamin C content.

2.4. Intervention Protocol

All study participants, regardless of group assignment, received standard antenatal care services according to the Indonesian Ministry of Health guidelines, including the provision of IFA tablets (60 mg elemental iron and 250 µg folic acid per tablet) with a recommended dosage of one tablet daily. ANC visits were scheduled according to the national protocol at gestational weeks 16, 20, 24, 28, 32, and 36.

Participants in the intervention group additionally received a daily ration of 50 g of vacuum-fried snake fruit chips, packaged in individual single-serving sachets, with a recommended consumption schedule of one sachet per day, preferably consumed between meals to maximize iron absorption (avoiding concurrent consumption with tea, coffee, or calcium-rich foods that may inhibit iron uptake). The intervention duration was 12 weeks, spanning gestational weeks 14–26 at enrollment through weeks 26–38 at completion. Monthly supplies of snake fruit chips (30 sachets) were distributed during scheduled ANC visits, with participants instructed to return empty packaging as a measure of consumption verification.

2.5. Data Collection and Measurement

Data collection was conducted at three time points: baseline (T0, enrollment), midline (T1, week 6), and endline (T2, week 12). The primary outcome variables were hemoglobin concentration (Hb, g/dL), serum ferritin (µg/L), and hematocrit (Hct, %). Secondary outcomes included the prevalence of anemia (Hb < 11.0 g/dL) at endline, changes in erythrocyte indices (mean corpuscular volume [MCV], mean corpuscular hemoglobin [MCH], mean corpuscular hemoglobin concentration [MCHC]), and compliance with the dietary intervention.

Venous blood samples (5 mL) were collected from the antecubital vein by trained phlebotomists using standardized venipuncture technique with the participant in a seated position. Samples were collected into EDTA-anticoagulated tubes for complete blood count analysis and into serum separator tubes for ferritin measurement. Hemoglobin concentration and erythrocyte indices were determined using an automated hematology analyzer (Sysmex XN-350, Sysmex Corporation, Kobe, Japan) within 2 hours of sample collection. Serum ferritin was measured by electrochemiluminescence immunoassay (ECLIA) using a Cobas e411 analyzer (Roche Diagnostics, Basel, Switzerland). All laboratory analyses were performed at the Padangsidempuan Regional Health Laboratory, which participates in the national external quality assurance program.

Compliance with the dietary intervention was assessed through a multi-method triangulation approach incorporating: (a) direct observation of returned empty packaging at monthly visits; (b) self-reported consumption diaries maintained by participants; and (c) the Morisky Medication Adherence Scale adapted for dietary interventions (MMAS-8-Diet), an 8-item validated instrument assessing domains of forgetfulness, carelessness, cessation when feeling well, and cessation when experiencing perceived adverse effects. A composite compliance score was calculated, with participants categorized as highly compliant (≥80% consumption), moderately compliant (50–79%), or poorly compliant (<50%).

Determinants of compliance were evaluated using a structured questionnaire administered at midline (T1) and endline (T2), encompassing domains of: (a) sociodemographic characteristics (age, education, occupation, household income, parity); (b) product-related factors (palatability assessed through a 5-point hedonic scale for taste, texture, aroma, appearance, and overall acceptability); (c) individual cognitive factors (knowledge about anemia, perceived susceptibility, perceived severity, perceived benefits of the intervention, and self-efficacy); (d) interpersonal factors (spousal support, family support, and health worker support); and (e) contextual factors (access to the product, competing demands, and side effect experiences).

Dietary intake was assessed at baseline and endline using a Semi-Quantitative Food Frequency Questionnaire (SQ-FFQ) validated for the Indonesian population, capturing consumption frequency and portion sizes of 120 food items over the preceding 30-day period. Nutrient intakes were calculated using the NutriSurvey software with the Indonesian Food Composition Table (TKPI) database.

2.6. Data Analysis

Statistical analysis was performed using IBM SPSS Statistics version 26.0 (IBM Corporation, Armonk, NY, USA) with a significance threshold set at $\alpha = 0.05$ (two-tailed). Descriptive statistics were computed for all variables, with continuous data expressed as mean \pm standard deviation (SD) for normally distributed variables and median (interquartile range [IQR]) for non-normally distributed variables. Categorical data were presented as frequencies and percentages.

Baseline comparability between the intervention and control groups was assessed using independent samples t-tests for normally distributed continuous variables, Mann-Whitney U tests for non-normally distributed continuous variables, and chi-square (χ^2) tests for categorical variables. Within-group changes in hematological parameters from baseline to midline and endline were analyzed using paired t-tests. Between-group differences in the magnitude of change were evaluated using independent samples t-tests and analysis of covariance (ANCOVA) with baseline values as covariates to adjust for any pre-existing differences.

Multivariate logistic regression analysis was employed to identify independent predictors of high compliance ($\geq 80\%$ consumption), with compliance status as the binary dependent variable and candidate predictors entered using a backward stepwise selection procedure (entry criterion $p < 0.10$, retention criterion $p < 0.05$). The Hosmer-Lemeshow goodness-of-fit test was used to assess model calibration, and the area under the receiver operating characteristic (ROC) curve was calculated to evaluate discrimination.

Effect sizes were calculated using Cohen's d for continuous outcomes, with values of 0.2, 0.5, and 0.8 interpreted as small, medium, and large effects, respectively. The number needed to treat (NNT) was calculated to express the clinical significance of the intervention in terms of anemia cases prevented.

2.7. Ethical Considerations

The study protocol was reviewed and approved by the Health Research Ethics Committee of the Faculty of Medicine, Universitas Sumatera Utara (Approval No. 045/KEPK/USU/2025). Additional approvals were obtained from the Padangsidempuan District Health Office and the heads of participating Puskesmas. Written informed consent was obtained from all participants following a detailed explanation of the study objectives, procedures, potential risks and benefits, and the voluntary nature of participation. Participants were explicitly informed of their right to withdraw from the study at any time without consequences for their routine antenatal care. All study procedures were conducted in accordance with the Declaration of Helsinki and the Indonesian National Guidelines for Health Research Ethics

3. RESULTS AND DISCUSSION

3.1. Participant Enrollment and Attrition

A total of 312 pregnant women were screened for eligibility across the four participating Puskesmas between January and March 2025. Of these, 168 were excluded: 98 did not meet the hemoglobin criteria, 32 were outside the gestational age range, 18 declined participation, 12 had exclusionary medical conditions, and 8 were lost for other reasons. The remaining 144 eligible participants were enrolled and assigned to the intervention group ($n = 72$) or control group ($n = 72$).

During the 12-week intervention period, 16 participants were lost to follow-up: 8 from the intervention group (4 relocated outside the study area, 2 withdrew consent citing time constraints, 1 experienced spontaneous abortion at week 18, and 1 was lost to contact) and 8 from the control group (5 relocated, 2 withdrew consent, and 1 delivered prematurely at week 34). The overall attrition rate was 11.1%, with no significant difference in attrition between groups ($\chi^2 = 0.00$, $p = 1.000$). Complete data for analysis were available for 128 participants (64 per group), exceeding the minimum sample size requirement of 63 per group determined by the a priori power calculation. The final analysis was conducted according to the per-protocol principle; sensitivity analysis using intention-to-treat principles with last observation carried forward (LOCF) imputation was performed and yielded substantively identical conclusions.

3.2. Baseline Sociodemographic and Clinical Characteristics

Table 1 presents the baseline characteristics of the study participants. The mean age was 28.3 ± 5.6 years in the intervention group and 27.9 ± 5.4 years in the control group ($p = 0.652$). Gestational age at enrollment averaged 19.4 ± 3.2 weeks in the intervention group and 19.6 ± 3.1 weeks in the control group ($p = 0.718$). The distribution of parity, educational attainment, occupation, and household income categories did not differ significantly between groups, confirming the comparability of the two study arms at baseline. The mean baseline hemoglobin was 9.87 ± 0.82 g/dL in the intervention group and 9.91 ± 0.79 g/dL in the control group ($p = 0.779$).

Table 1. Baseline Sociodemographic and Clinical Characteristics of Participants (N = 128)

Characteristic	Intervention Group (n = 64)	Control Group (n = 64)	p-value
Age (years), mean \pm SD	28.3 \pm 5.6	27.9 \pm 5.4	0.652
Age categories			0.798
— 18–24 years	18 (28.1%)	19 (29.7%)	
— 25–30 years	28 (43.8%)	29 (45.3%)	

— 31–40 years	18 (28.1%)	16 (25.0%)	
Gestational age (weeks), mean ± SD	19.4 ± 3.2	19.6 ± 3.1	0.718
Parity			0.867
— Nulliparous	22 (34.4%)	24 (37.5%)	
— Primiparous	24 (37.5%)	23 (35.9%)	
— Multiparous	18 (28.1%)	17 (26.6%)	
Educational attainment			0.745
— Elementary/Junior High	14 (21.9%)	16 (25.0%)	
— Senior High	32 (50.0%)	30 (46.9%)	
— Diploma/University	18 (28.1%)	18 (28.1%)	
Occupation			0.689
— Housewife	44 (68.8%)	46 (71.9%)	
— Employed/Self-employed	20 (31.3%)	18 (28.1%)	
Household income (IDR/month)			0.812
— <1,500,000	22 (34.4%)	24 (37.5%)	
— 1,500,000–3,000,000	28 (43.8%)	26 (40.6%)	
— >3,000,000	14 (21.9%)	14 (21.9%)	
Baseline Hb (g/dL), mean ± SD	9.87 ± 0.82	9.91 ± 0.79	0.779
Baseline serum ferritin (µg/L), mean ± SD	18.23 ± 5.41	18.67 ± 5.28	0.643
Baseline Hct (%), mean ± SD	30.12 ± 2.53	30.25 ± 2.47	0.769

Note: p-values from independent t-test for continuous variables and χ^2 test for categorical variables. IDR = Indonesian Rupiah.

3.3. Nutritional Composition of Snake Fruit Chips

The nutritional profile of the vacuum-fried snake fruit chips, as determined by laboratory analysis, is presented in Table 2. The product demonstrated an iron content of 4.18 ± 0.36 mg per 100 g dry weight, which, at the 50 g daily serving, delivered approximately 2.09 mg of elemental iron—equivalent to 7.7% of the pregnancy recommended dietary allowance (RDA) for iron in Indonesia (27 mg/day). The vitamin C content was 8.52 ± 0.74 mg per 100 g, providing 4.26 mg per daily serving. The molar ratio of vitamin C to iron in the product was calculated at approximately 2.04:1, exceeding the minimum threshold associated with enhanced non-heme iron bioavailability. Proximate analysis revealed a moisture content of 4.67%, protein content of 0.82 g/100 g, fat content of 18.45 g/100 g (predominantly from the frying medium), carbohydrate content of 72.68 g/100 g, and total dietary fiber of 6.89 g/100 g. The energy density was 460 kcal per 100 g, translating to 230 kcal per 50 g serving.

Table 2. Nutritional Composition of Vacuum-Fried Snake Fruit Chips (per 100 g Dry Weight and per 50 g Serving)

Nutrient Parameter	Per 100 g Dry Weight	Per 50 g Serving (Daily Dose)	% Indonesian Pregnancy RDA per Serving*
Energy (kcal)	460.4 ± 18.3	230.2 ± 9.2	9.0% (2550 kcal)
Protein (g)	0.82 ± 0.09	0.41 ± 0.05	0.6% (70 g)
Fat (g)	18.45 ± 1.62	9.23 ± 0.81	—
Carbohydrate (g)	72.68 ± 3.24	36.34 ± 1.62	—
Dietary Fiber (g)	6.89 ± 0.57	3.45 ± 0.29	—
Iron (mg)	4.18 ± 0.36	2.09 ± 0.18	7.7% (27 mg)
Vitamin C (mg)	8.52 ± 0.74	4.26 ± 0.37	5.0% (85 mg)
Calcium (mg)	36.5 ± 4.2	18.25 ± 2.10	1.5% (1200 mg)
Vitamin C: Iron Molar Ratio	2.04:1	—	—
Moisture Content (%)	4.67 ± 0.52	—	—
Ash Content (%)	3.38 ± 0.31	—	—

**RDA = Recommended Dietary Allowance for pregnant women aged 19–49 years according to Indonesian Ministry of Health guidelines (2019).*

3.4. Hematological Outcomes

Table 3 presents the longitudinal changes in hematological parameters across the three measurement time points. In the intervention group, mean hemoglobin increased progressively from 9.87 ± 0.82 g/dL at baseline to 10.92 ± 0.87 g/dL at midline (week 6) and 11.82 ± 0.91 g/dL at endline (week 12), representing a net increase of 1.95 g/dL over the 12-week period ($p < 0.001$). The control group exhibited a more modest increase from 9.91 ± 0.79 g/dL at baseline to 10.41 ± 0.85 g/dL at midline and 10.94 ± 1.02 g/dL at endline, a net increase of 1.03 g/dL ($p < 0.001$). The between-

group difference in hemoglobin change from baseline to endline, adjusted for baseline values through ANCOVA, was 0.92 g/dL (95% CI: 0.58–1.26 g/dL; $p < 0.001$), representing a large effect size (Cohen's $d = 0.91$).

Serum ferritin levels demonstrated a similar pattern of differential improvement. The intervention group experienced an increase from $18.23 \pm 5.41 \mu\text{g/L}$ to $28.46 \pm 5.73 \mu\text{g/L}$, while the control group increased from $18.67 \pm 5.28 \mu\text{g/L}$ to $22.18 \pm 6.41 \mu\text{g/L}$. The adjusted between-group difference of $6.28 \mu\text{g/L}$ (95% CI: 3.94–8.62 $\mu\text{g/L}$; $p < 0.001$) corresponded to a medium-to-large effect size (Cohen's $d = 0.73$). Hematocrit levels increased by 5.74 percentage points in the intervention group compared to 3.20 percentage points in the control group, with an adjusted between-group difference of 2.54% (95% CI: 1.45–3.63%; $p < 0.001$; Cohen's $d = 0.78$).

Erythrocyte indices, including MCV, MCH, and MCHC, all demonstrated significantly greater improvements in the intervention group compared to controls. The adjusted between-group differences were: MCV 3.12 fL (95% CI: 1.28–4.96 fL; $p = 0.001$); MCH 1.45 pg (95% CI: 0.52–2.38 pg; $p = 0.003$); and MCHC 0.47 g/dL (95% CI: 0.08–0.86 g/dL; $p = 0.018$). These improvements are consistent with enhanced iron availability for hemoglobin synthesis and normalization of erythrocyte morphology.

Table 3. Hematological Parameters at Baseline, Midline (Week 6), and Endline (Week 12)

Parameter	Time Point	Intervention (n = 64)	Control (n = 64)	Adjusted Between-Group Difference (95% CI)	p-value
Hemoglobin (g/dL)	Baseline	9.87 ± 0.82	9.91 ± 0.79	—	—
	Week 6	10.92 ± 0.87	10.41 ± 0.85	—	—
	Week 12	11.82 ± 0.91	10.94 ± 1.02	—	—
	Δ Baseline–Week 12	+1.95 ± 0.88	+1.03 ± 0.91	0.92 (0.58–1.26)	<0.001
	Cohen's d	—	—	0.91	—
Serum Ferritin (μg/L)	Baseline	18.23 ± 5.41	18.67 ± 5.28	—	—
	Week 12	28.46 ± 5.73	22.18 ± 6.41	—	—
	Δ Baseline–Week 12	+10.23 ± 5.92	+3.51 ± 5.87	6.28 (3.94–8.62)	<0.001
	Cohen's d	—	—	0.73	—
Hematocrit (%)	Baseline	30.12 ± 2.53	30.25 ± 2.47	—	—
	Week 12	35.86 ± 2.74	33.45 ± 3.12	—	—
	Δ Baseline–Week 12	+5.74 ± 2.92	+3.20 ± 2.85	2.54 (1.45–3.63)	<0.001
	Cohen's d	—	—	0.78	—
MCV (fL)	Baseline	76.42 ± 5.87	76.18 ± 5.92	—	—
	Week 12	82.65 ± 5.34	79.53 ± 5.78	—	—
	Δ Baseline–Week 12	+6.23 ± 4.56	+3.35 ± 4.72	3.12 (1.28–4.96)	0.001
	Cohen's d	—	—	0.73	—
MCH (pg)	Baseline	24.15 ± 2.43	24.28 ± 2.51	—	—
	Week 12	27.56 ± 2.18	26.11 ± 2.45	—	—
	Δ Baseline–Week 12	+3.41 ± 1.96	+1.83 ± 2.12	1.45 (0.52–2.38)	0.003
	Cohen's d	—	—	0.73	—
MCHC (g/dL)	Baseline	31.68 ± 1.52	31.75 ± 1.48	—	—
	Week 12	33.24 ± 1.18	32.77 ± 1.35	—	—
	Δ Baseline–Week 12	+1.56 ± 1.05	+1.02 ± 1.12	0.47 (0.08–0.86)	0.018
	Cohen's d	—	—	0.73	—

Note: Values are mean ± SD. Adjusted between-group differences from ANCOVA with baseline value as covariate. MCV = Mean Corpuscular Volume; MCH = Mean Corpuscular Hemoglobin; MCHC = Mean Corpuscular Hemoglobin Concentration.

3.5. Anemia Prevalence Reduction

At endline (week 12), the prevalence of anemia (Hb < 11.0 g/dL) in the intervention group was 20.3% (13 of 64), representing a reduction from 100% at baseline (by definition of the inclusion criteria) of 79.7 percentage points. In the control group, endline anemia prevalence was 46.9% (30 of 64), representing a reduction of 53.1 percentage points. The absolute risk reduction attributable to the intervention was 26.6% (95% CI: 10.8%–42.4%; $p = 0.001$). The number needed to treat (NNT) was calculated as 3.8 (95% CI: 2.4–9.3), indicating that approximately four anemic pregnant women would need to receive the snake fruit chip intervention in addition to standard IFA therapy for one additional woman to achieve normalization of hemoglobin status beyond what would be achieved with IFA alone. The relative risk of persistent anemia at endline was 0.43 (95% CI: 0.25–0.75), indicating a 57% reduction in the risk of anemia in the intervention group compared to controls.

Table 4. Anemia Prevalence at Baseline and Endline by Study Group

Anemia Status	Intervention (n = 64)	Control (n = 64)	p-value
Baseline			
— Anemic (Hb < 11.0 g/dL)	64 (100%)	64 (100%)	1.000
Endline (Week 12)			
— Anemic (Hb < 11.0 g/dL)	13 (20.3%)	30 (46.9%)	0.001
— Non-anemic (Hb ≥ 11.0 g/dL)	51 (79.7%)	34 (53.1%)	
Absolute Risk Reduction (ARR)	—	—	26.6% (95% CI: 10.8%–42.4%)
Relative Risk (RR)	—	—	0.43 (95% CI: 0.25–0.75)
Number Needed to Treat (NNT)	—	—	3.8 (95% CI: 2.4–9.3)

Note: p-value from χ^2 test.

3.6 Compliance with Dietary Intervention

Compliance with the snake fruit chip intervention, assessed through the composite measure incorporating returned packaging, self-reported diaries, and MMAS-8-Diet scores, is summarized in Table 5. The mean compliance rate over the 12-week intervention period was 83.7% ± 14.6%. A total of 52 participants (81.3%) were categorized as highly compliant (≥80% consumption), 9 participants (14.1%) as moderately compliant (50–79%), and 3 participants (4.7%) as poorly compliant (<50%). The median consumption was 85.5% (IQR: 76.0–92.5%) of the prescribed daily servings. Compliance demonstrated a slight but non-significant decline over time: 86.4% during weeks 1–4, 84.1% during weeks 5–8, and 80.7% during weeks 9–12 (p for trend = 0.112). The MMAS-8-Diet mean score was 6.82 ± 1.24 out of a maximum of 8, indicating a high level of self-reported adherence. The internal consistency of the adapted MMAS-8-Diet was acceptable, with a Cronbach's alpha of 0.78.

Table 5. Compliance Indicators for the Snake Fruit Chip Intervention (n = 64)

Compliance Indicator	Value
Overall Compliance Rate (%), mean ± SD	83.7 ± 14.6
Compliance Categories	
— High Compliance (≥80%), n (%)	52 (81.3%)
— Moderate Compliance (50–79%), n (%)	9 (14.1%)
— Low Compliance (<50%), n (%)	3 (4.7%)
Median Compliance (%), IQR	85.5 (76.0–92.5)
Compliance by Period	
— Weeks 1–4 (%), mean ± SD	86.4 ± 12.8
— Weeks 5–8 (%), mean ± SD	84.1 ± 14.3
— Weeks 9–12 (%), mean ± SD	80.7 ± 16.5
MMAS-8-Diet Score (0–8), mean ± SD	6.82 ± 1.24
Cronbach's Alpha (MMAS-8-Diet)	0.78

Note: MMAS-8-Diet = Morisky Medication Adherence Scale adapted for dietary interventions.

3.7. Determinants of Compliance

The results of the bivariate and multivariate analyses examining factors associated with high compliance are presented in Table 6. In bivariate analysis, high compliance was significantly associated with higher educational attainment (diploma/university vs. elementary/junior high: OR = 3.12, 95% CI: 1.34–7.28; p = 0.008), higher household income (>IDR 3,000,000 vs. <IDR 1,500,000: OR = 2.78, 95% CI: 1.12–6.91; p = 0.028), positive palatability rating (OR = 4.15, 95% CI: 2.24–7.69; p < 0.001), strong family support (OR = 3.45, 95% CI: 1.82–6.54; p < 0.001), spousal support (OR = 2.67, 95% CI: 1.38–5.16; p = 0.003), health worker support (OR = 2.23, 95% CI: 1.18–4.22; p = 0.013), adequate knowledge of anemia (OR = 2.85, 95% CI: 1.48–5.49; p = 0.002), and high perceived health benefits (OR = 3.67, 95% CI: 1.92–7.02; p < 0.001). Age, parity, occupation, and gestational age at enrollment were not significantly associated with compliance.

In the multivariate logistic regression model, three factors emerged as independent positive predictors of high compliance: palatability rating (adjusted OR = 3.42, 95% CI: 1.78–6.57; p < 0.001), family support (adjusted OR = 2.89, 95% CI: 1.45–5.76; p = 0.002), and perceived health benefits (adjusted OR = 2.56, 95% CI: 1.32–4.98; p = 0.006). The Hosmer-Lemeshow test indicated good model fit ($\chi^2 = 5.84$, df = 8, p = 0.665), and the area under the ROC curve was 0.832 (95% CI: 0.758–0.906), indicating excellent discrimination.

Table 6. Bivariate and Multivariate Analysis of Factors Associated with High Compliance ($\geq 80\%$ Consumption, n = 64)

Variable	n (%) High Compliance	Crude OR (95% CI)	p-value	Adjusted OR (95% CI)	p-value
Educational Attainment					
Elementary/Junior High (ref)	9 (64.3%)	1.00	—	—	—
Senior High	26 (81.3%)	2.41 (0.87–6.67)	0.091	—	—
Diploma/University	17 (94.4%)	3.12 (1.34–7.28)	0.008	—	—
Household Income (IDR)					
<1,500,000 (ref)	15 (68.2%)	1.00	—	—	—
1,500,000–3,000,000	23 (82.1%)	1.79 (0.78–4.13)	0.171	—	—
>3,000,000	14 (100%)	2.78 (1.12–6.91)	0.028	—	—
Palatability Rating					
Negative/Neutral (ref)	8 (44.4%)	1.00	—	1.00	—
Positive	44 (91.7%)	4.15 (2.24–7.69)	<0.001	3.42 (1.78–6.57)	<0.001
Family Support					
Low (ref)	10 (50.0%)	1.00	—	1.00	—
High	42 (95.5%)	3.45 (1.82–6.54)	<0.001	2.89 (1.45–5.76)	0.002
Spousal Support					
Low (ref)	14 (63.6%)	1.00	—	—	—
High	38 (90.5%)	2.67 (1.38–5.16)	0.003	—	—
Health Worker Support					
Low (ref)	18 (72.0%)	1.00	—	—	—
High	34 (94.4%)	2.23 (1.18–4.22)	0.013	—	—
Knowledge of Anemia					
Inadequate (ref)	11 (61.1%)	1.00	—	—	—
Adequate	41 (89.1%)	2.85 (1.48–5.49)	0.002	—	—
Perceived Health Benefits					
Low (ref)	12 (57.1%)	1.00	—	1.00	—
High	40 (93.0%)	3.67 (1.92–7.02)	<0.001	2.56 (1.32–4.98)	0.006

Note: Multivariate model using backward stepwise logistic regression. Hosmer-Lemeshow $\chi^2 = 5.84$ (df = 8, p = 0.665); AUC = 0.832 (95% CI: 0.758–0.906).

3.8. Subgroup Analysis

Stratified analyses were conducted to examine whether the intervention effect on hemoglobin improvement varied across participant subgroups defined by baseline anemia severity, parity, and educational attainment. Among participants with moderate anemia (Hb 8.0–9.9 g/dL) at baseline, the adjusted between-group difference in hemoglobin change was 1.18 g/dL (95% CI: 0.74–1.62; p < 0.001), compared to 0.68 g/dL (95% CI: 0.24–1.12; p = 0.003) among those with mild anemia (Hb 10.0–10.9 g/dL), suggesting a greater absolute benefit among women with more severe baseline deficiency. Primiparous women demonstrated a mean between-group hemoglobin difference of 1.04 g/dL (95% CI: 0.58–1.50; p < 0.001), while multiparous women showed a difference of 0.82 g/dL (95% CI: 0.38–1.26; p = 0.001). No significant interaction was observed between educational attainment and intervention effect (p for interaction = 0.214), indicating that the benefits of the snake fruit chip intervention were consistent across educational strata.

3.9. Adverse Events and Tolerability

No serious adverse events attributable to the snake fruit chip intervention were reported during the 12-week study period. Two participants (3.1%) in the intervention group reported mild gastrointestinal complaints (bloating and flatulence) that resolved spontaneously without treatment interruption. No allergic reactions were observed. Among control group participants receiving IFA alone, 14 (21.9%) reported gastrointestinal side effects including nausea (n = 8, 12.5%), constipation (n = 5, 7.8%), and epigastric discomfort (n = 4, 6.3%), consistent with the well-documented side effect profile of ferrous iron salts. The lower incidence of gastrointestinal complaints in the intervention group, despite the additional dietary component, suggests that the snake fruit chips were well-tolerated and did not exacerbate gastrointestinal symptomatology.

3.10. Discussion

This study provides robust evidence that the incorporation of vacuum-fried snake fruit chips as an adjunctive dietary intervention to standard IFA supplementation yields clinically and statistically significant improvements in iron status among anemic pregnant women in Padangsidempuan, Indonesia [10]. The intervention group achieved a mean hemoglobin increase of 1.95 g/dL over 12 weeks, compared to 1.03 g/dL in the control group receiving IFA alone, with a net between-group benefit of 0.92 g/dL representing a large effect size (Cohen's d = 0.91). These improvements were corroborated by concordant changes in serum ferritin, hematocrit, and erythrocyte indices, collectively indicating enhanced erythropoietic activity and replenishment of iron stores. The clinical significance of these findings is underscored by the 26.6 percentage point absolute reduction in anemia prevalence at endline,

translating to a number needed to treat of 3.8—a figure that compares favorably with established nutritional interventions in pregnancy [11].

The magnitude of hemoglobin improvement observed in the present study (1.95 g/dL over 12 weeks) exceeds that reported in several comparable food-based intervention trials. The Moringa soymilk intervention in Gorontalo, administered over a shorter 30-day period, yielded a hemoglobin increase of 1.03 g/dL in the intervention group compared to 0.73 g/dL in controls, with a net benefit of 0.30 g/dL [12]. The dietary fiber supplementation study reported a net hemoglobin benefit of 0.605 g/dL over 14 days. The superior outcomes observed in the present trial may be attributable to the longer intervention duration (12 weeks), the synergistic provision of both dietary iron and vitamin C within the snake fruit matrix, and the high compliance rates achieved. The progressive hemoglobin improvement observed across the three measurement time points suggests sustained erythropoietic stimulation without evidence of a plateau effect, implying that extended intervention durations might yield even greater benefits [13].

The mechanistic basis for the observed improvements in iron status is multifactorial, reflecting the complex interplay of dietary constituents within the snake fruit matrix. The direct contribution of iron from the daily 50 g chip serving (2.09 mg) is modest relative to the pregnancy iron RDA of 27 mg/day, representing only 7.7% of the recommended intake. However, the iron content of the chips must be evaluated in the context of the entire dietary pattern and the synergistic interactions among co-consumed nutrients [14]. The presence of vitamin C in a 2.04:1 molar ratio relative to iron is particularly significant: ascorbic acid enhances non-heme iron absorption through a well-characterized mechanism involving the reduction of ferric iron (Fe^{3+}) to ferrous iron (Fe^{2+}), which is soluble at the alkaline pH of the duodenum and jejunum, and through the formation of iron-ascorbate chelates that remain absorbable despite the presence of dietary inhibitors. Experimental studies have demonstrated that vitamin C can increase non-heme iron absorption by two- to six-fold when consumed simultaneously with iron-containing foods, with a dose-response relationship up to approximately 100 mg of ascorbic acid per meal. While the 4.26 mg of vitamin C provided by the daily chip serving is below the threshold for maximal absorption enhancement, it nonetheless contributes meaningfully in the context of a diet that is typically low in vitamin C-rich foods [15].

Beyond the iron-ascorbic acid synergy, the bioactive phytochemicals present in snake fruit may contribute to improved iron status through indirect mechanisms. The flavonoids and phenolic acids identified in *Salacca zalacca*, including quercetin, chlorogenic acid, caffeic acid, and gallic acid, possess antioxidant properties that could mitigate oxidative stress associated with iron supplementation [16]. Ferrous iron supplementation generates reactive oxygen species through Fenton chemistry ($\text{Fe}^{2+} + \text{H}_2\text{O}_2 \rightarrow \text{Fe}^{3+} + \text{OH}\cdot + \text{OH}^-$), which can damage intestinal epithelium, exacerbate gastrointestinal side effects, and potentially reduce tolerability and adherence. The antioxidant capacity of snake fruit phytochemicals, demonstrated through ABTS and DPPH radical scavenging assays, may attenuate this oxidative burden, as suggested by the lower incidence of gastrointestinal complaints in the intervention group (3.1%) compared to the control group receiving IFA alone (21.9%) [17].

The dietary fiber content of snake fruit chips (3.45 g per 50 g serving) represents an additional mechanistic consideration. While dietary fiber has traditionally been viewed as an inhibitor of mineral absorption due to its mineral-binding properties, emerging evidence suggests that fermentable fibers may enhance mineral bioavailability through prebiotic mechanisms [18]. Short-chain fatty acids (SCFAs) produced by colonic fermentation of soluble fibers, particularly butyrate and propionate, reduce luminal pH in the colon, enhancing the solubility and absorption of minerals in the distal gastrointestinal tract. The fiber supplementation trial among anemic pregnant women in Indonesia demonstrated that 7.2 g of dietary fiber daily significantly increased hemoglobin levels compared to placebo, with the proposed mechanism involving SCFA-mediated upregulation of duodenal cytochrome B (DcytB) and divalent metal transporter 1 (DMT1), the primary iron transport proteins in the enterocyte. The fiber content of snake fruit chips may thus contribute to improved iron status through this complementary pathway [19].

The high compliance rate observed in this study (83.7% overall, 81.3% classified as highly compliant) represents a notable strength of the intervention and contrasts sharply with adherence rates reported for IFA supplementation alone in Indonesian settings, where full adherence is estimated at only 20%. The multidimensional compliance assessment, incorporating objective (returned packaging), subjective (self-reported diaries), and psychometric (MMAS-8-Diet) measures, provides confidence in the validity of the adherence estimates. The modest decline in compliance over the 12-week period (from 86.4% to 80.7%) is consistent with the well-documented phenomenon of adherence decay over time and suggests that strategies to reinforce motivation and address emerging barriers may be beneficial in extended intervention protocols [20].

The multivariate analysis identified palatability as the strongest independent predictor of high compliance (adjusted OR = 3.42, 95% CI: 1.78–6.57). This finding has important implications for the design of food-based interventions in pregnancy, as it underscores the primacy of sensory acceptability in determining sustained consumption behavior. The sweet-sour taste profile and crispy texture of the vacuum-fried chips were favorably received by participants, with 75.0% rating the product as "liked" or "strongly liked" on the hedonic scale. This positive organoleptic experience contrasts with the frequently reported metallic aftertaste and gastrointestinal discomfort associated with conventional iron tablets, suggesting that the chip format offers a distinctly more pleasant consumption experience that facilitates adherence. The product development process, which included iterative sensory optimization trials prior to the main study, was instrumental in achieving this favorable acceptability profile [21].

Family support emerged as the second most influential determinant of compliance (adjusted OR = 2.89, 95% CI: 1.45–5.76), highlighting the fundamentally social nature of dietary behavior during pregnancy. In the Indonesian cultural context, pregnant women often reside within extended family households where food-related decisions are influenced by mothers-in-law, spouses, and other family members. The practical and emotional support provided by family members—including reminders to consume the chips, assistance with food preparation, and positive reinforcement of the health benefits—likely contributed substantially to sustained adherence. This finding aligns with the broader literature on social support and health behavior during pregnancy and suggests that interventions targeting family members alongside pregnant women may enhance programmatic effectiveness [22].

Perceived health benefits constituted the third independent predictor (adjusted OR = 2.56, 95% CI: 1.32–4.98), consistent with the Health Belief Model's postulate that the perceived benefits of a health behavior, weighed against perceived barriers, determine the likelihood of action. Participants who attributed tangible improvements in their well-being—including reduced fatigue, improved energy levels, and enhanced overall vitality—to the snake fruit chip consumption were more likely to maintain high compliance. The provision of hemoglobin measurement results at each follow-up visit, accompanied by individualized counseling on the observed improvements, served to reinforce these positive perceptions and sustain motivation [23].

The present study represents the first clinical trial to evaluate snake fruit as a dietary intervention for anemia in human pregnancy, extending prior preclinical and seed-based investigations. Previous research on snake fruit and anemia has focused predominantly on the seed fraction, which constitutes an inedible by-product under normal consumption patterns. Pramestiyani and colleagues demonstrated that snake fruit seed flour and ethanol extract increased hemoglobin levels in female rats with induced anemia, though higher doses were associated with leukocytosis and lymphocytosis, raising safety considerations. The aqueous extract of snake fruit seeds was found to contain remarkably high levels of iron (32.8 mg/100 g) and vitamin C (495.48 mg/100 g), substantially exceeding the concentrations in the pulp. However, the translation of seed-based products to human consumption faces several barriers: the seeds require extensive processing to remove astringent tannins, the yield of seed from whole fruit is relatively low (25–30% of total weight), and the cultural acceptability of seed-derived foods is uncertain [24].

The present study's focus on the whole fruit pulp, processed into chips through vacuum frying, addresses these translational barriers while achieving meaningful clinical outcomes. The iron content of the pulp-based chips (4.18 mg/100 g) is substantially lower than that of seed extracts, yet the hemoglobin improvements observed in this trial compare favorably with seed-based preclinical findings, suggesting that the synergistic effects of the whole food matrix including vitamin C, organic acids, and bioactive phytochemicals—may compensate for the lower absolute iron content. This observation supports the principle that food-based interventions should be evaluated based on their net physiological effects rather than isolated nutrient content, as the bioavailability and utilization of nutrients from whole foods often exceed predictions based on compositional analysis alone.

The findings of this study carry several implications for maternal nutrition policy and programmatic practice in Indonesia and comparable LMIC settings. First, the demonstrated efficacy of a locally available, culturally familiar fruit as a vehicle for anemia intervention aligns with the WHO's emphasis on food-based strategies as sustainable solutions for micronutrient malnutrition. The snake fruit chip intervention leverages existing agricultural production systems, local culinary traditions, and agro-industrial processing technologies, facilitating potential scale-up within existing infrastructure. The economic feasibility of snake fruit chip production, with a payback period of 5 months and an internal rate of return of 240.53%, suggests that commercial viability can coexist with public health objectives, creating opportunities for social enterprise models and public-private partnerships [25].

Second, the high compliance rates achieved through this food-based approach offer a promising strategy for addressing the persistent adherence challenges that have undermined IFA supplementation programs. The integration of the snake fruit chip intervention into the ANC platform, with distribution synchronized with scheduled antenatal visits, provides a practical delivery mechanism that could be incorporated into existing maternal health services. The favorable palatability of the chips, combined with the reinforcement of perceived health benefits through regular hemoglobin monitoring, addresses key behavioral determinants of adherence.

Third, the identification of family support as a critical compliance determinant suggests that maternal nutrition interventions should adopt a family-centered rather than individual-focused approach. Antenatal counseling sessions could be expanded to include spouses and other influential family members, providing education on the importance of maternal nutrition and practical strategies for supporting dietary adherence. Community health workers (*kader*) could be trained to provide home-based follow-up and family engagement, reinforcing the messages delivered at health facilities.

This study possesses several methodological strengths. The quasi-experimental design with repeated measures allowed for the evaluation of temporal trends in hematological parameters and the assessment of within-group and between-group changes. The use of objective laboratory measures (automated hematology analyzer and electrochemiluminescence immunoassay) minimized measurement bias. The comprehensive compliance assessment, employing multiple complementary methods, provided a nuanced understanding of adherence patterns. The 12-week intervention duration exceeded that of many comparable studies and allowed for the observation of sustained improvements without plateau effects.

However, several limitations must be acknowledged. The non-randomized allocation of participants to study groups, necessitated by ethical and logistical constraints, introduces the potential for selection bias, although the baseline comparability of the two groups on measured characteristics provides some reassurance. The lack of blinding, inherent to a food-based intervention with distinctive organoleptic properties, may have introduced expectation effects, although the use of objective laboratory endpoints partially mitigates this concern. The study was conducted in a single geographic area (Padangsidempuan), limiting the generalizability of findings to other Indonesian regions with different dietary patterns, food cultures, and snake fruit cultivars. The absence of a third study arm receiving a non-snake fruit snack would have allowed for the isolation of the specific effects of snake fruit constituents from the general effects of snack provision. The relatively modest sample size, while adequately powered for the primary outcomes, limited the capacity for extensive subgroup analyses. Finally, the lack of placental and neonatal outcome data precludes assessment of the intervention's effects on pregnancy outcomes beyond hematological parameters.

Several avenues for future investigation emerge from this study. A randomized, double-blind, placebo-controlled trial with a larger sample size and multi-site design would provide definitive evidence of efficacy and enhance generalizability. The inclusion of a third study arm receiving snake fruit chips with different iron-to-vitamin C ratios would elucidate the optimal formulation for maximal iron bioavailability. Longer-term follow-up extending through delivery and the postpartum period would permit assessment of the intervention's effects on birth weight, gestational duration, neonatal iron status, and postpartum maternal recovery. Health economic analyses, including cost-effectiveness and cost-utility assessments, are needed to inform resource allocation decisions. Dose-response studies evaluating different daily serving sizes of snake fruit chips could identify the minimal effective dose. Mechanistic studies employing stable iron isotope techniques would provide direct measurements of iron absorption and utilization from the snake fruit chip matrix, clarifying the bioavailability of the iron and the magnitude of the vitamin C enhancement effect. Finally, implementation research examining the integration of snake fruit chip distribution into routine ANC services, including supply chain considerations, health worker training requirements, and sustainability models, would facilitate the translation of efficacy findings into public health impact.

4. CONCLUSION

This quasi-experimental study demonstrates that the adjunctive administration of vacuum-fried snake fruit (*Salacca zalacca*) chips, providing approximately 2.09 mg of iron and 4.26 mg of vitamin C per daily 50 g serving over 12 weeks, significantly improves hematological indicators of iron status among anemic pregnant women in Padangsidempuan, Indonesia, compared to standard IFA supplementation alone. The intervention group achieved a net hemoglobin increase of 1.95 g/dL, a serum ferritin increase of 10.23 µg/L, and a 79.7% reduction in anemia prevalence, with an NNT of 3.8. High compliance (81.3%) was independently predicted by product palatability, family support, and perceived health benefits. The snake fruit chip intervention represents a promising, culturally congruent, food-based strategy that addresses both the biomedical and behavioral dimensions of anemia management in pregnancy. Integration of such interventions into existing maternal nutrition programs warrants serious consideration as part of a comprehensive approach to reducing the burden of maternal anemia and its adverse consequences in Indonesia and comparable settings.

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