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Mung bean (Vigna radiata) as a local functional food with potential for iron deficiency anaemia prevention: A narrative review of bioavailability mechanisms and food processing strategies

Kacang hijau (Vigna radiata) sebagai pangan fungsional lokal yang berpotensi untuk pencegahan anemia defisiensi besi: Tinjauan naratif mekanisme bioavailabilitas dan strategi teknologi pengolahan pangan

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Abstract

Background: Iron deficiency anemia (IDA) disproportionately affects adolescent girls and pregnant women. Food-based approaches using local resources complement pharmacological supplementation, which is limited by gastrointestinal adverse effects and poor adherence.
Objectives: This narrative review evaluates mung bean (*Vigna radiata*) as a local functional food with potential for IDA prevention, integrating nutritional composition, iron bioavailability mechanisms, clinical evidence, and processing strategies.
Methods: A purposive search of PubMed, Scopus, ScienceDirect, and SpringerLink was run in January 2025 and updated on April 30, 2026, prioritizing clinical publications from 2016 to 2026, with no date restriction on compositional sources. Twenty-nine sources were analyzed thematically across four domains; reporting quality was self-appraised using the SANRA.
Results: Mung bean contains 5.9–7.6 mg iron/100 g and 26.4% protein on a dry-weight basis, rising to 31.9% after 96 h of germination. Total vitamin C levels increased by approximately 78-fold during germination, reaching roughly 102 mg/100 g dry weight, though light-dependent. Raw seeds contained approximately 627 mg phytate/100 g; germination reduced this by 38.9%, cooking by 31–37%, and soaking by 27.8%, while lactic acid fermentation of cooked seed with buttermilk reduced phytic acid by up to 65.8% in vitro. Of seven Indonesian intervention studies, five with verifiable values showed hemoglobin increases of 0.74–3.50 g/dL over 3–14 days. Sample sizes, p-values, and between-group comparisons were reported inconsistently, and only one study compared intervention with control.
Conclusions: Mung beans show promising potential for IDA prevention, with fermentation being the best-supported processing strategy. Randomized trials using comprehensive iron status biomarkers are required.

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Keywords:
Functional food, iron bioavailability, iron deficiency anemia, mung bean, phytate reduction

Abstrak

Latar belakang: Anemia defisiensi besi (ADB) secara tidak proporsional berdampak pada remaja putri dan ibu hamil. Pendekatan berbasis pangan lokal melengkapi suplementasi farmakologis yang terkendala efek samping gastrointestinal dan rendahnya kepatuhan.
Tujuan: Tinjauan naratif ini mengevaluasi kacang hijau (Vigna radiata) sebagai pangan fungsional lokal yang berpotensi untuk pencegahan ADB, dengan mengintegrasikan komposisi gizi, mekanisme bioavailabilitas besi, bukti klinis, dan strategi pengolahan.
Metode: Penelusuran purposif pada PubMed, Scopus, ScienceDirect, dan SpringerLink dilakukan pada Januari 2025 dan diperbarui pada 30 April 2026, memprioritaskan publikasi klinis tahun 2016-2026, tanpa pembatasan tahun untuk sumber komposisi. Sebanyak 29 sumber dianalisis secara tematik pada empat domain, dan mutu pelaporan dinilai mandiri dengan skala SANRA enam item.
Hasil: Kacang hijau mengandung 5,9-7,6 mg besi/100 g dan protein 26,4% berat kering, meningkat menjadi 31,9% setelah perkecambahan 96 jam. Total vitamin C meningkat sekitar 78 kali lipat selama perkecambahan, mencapai sekitar 102 mg/100 g berat kering, meskipun bergantung pencahayaan. Biji mentah mengandung sekitar 627 mg fitat/100 g; perkecambahan menurunkannya 38,9%, pemasakan 31-37%, dan perendaman 27,8%, sedangkan fermentasi asam laktat dengan buttermilk menurunkan asam fitat hingga 65,8% secara in vitro. Dari tujuh studi intervensi di Indonesia, lima studi terverifikasi menunjukkan peningkatan hemoglobin 0,74-3,50 g/dL dalam 3-14 hari. Jumlah subjek, nilai p, dan perbandingan antarkelompok dilaporkan tidak konsisten, dan hanya satu studi yang membandingkan intervensi dengan kontrol.
Kesimpulan: Kacang hijau berpotensi untuk pencegahan ADB, dengan fermentasi sebagai strategi pengolahan yang paling didukung. Diperlukan uji klinis acak terkontrol dengan biomarker status besi yang komprehensif.

Kata Kunci:
Pangan fungsional, bioavailabilitas besi, anemia defisiensi besi, kacang hijau, penurunan fitat

Introduction

Adolescent girls and pregnant women are the most vulnerable populations to iron deficiency anemia (IDA) owing to elevated iron requirements during growth, menstruation, and pregnancy. Dietary patterns characterized by high consumption of low-nutrient-density foods further amplify this risk, particularly in low- and middle-income countries (Wiafe et al., 2023). Globally, the prevalence of anemia among women of reproductive age (15–49 years) is estimated at 30.7%, rising to 35.5% among pregnant women (World Health Organization, 2025). In Southeast Asia, the prevalence reaches 46.4%. In Indonesia, the National Basic Health Research 2018 reported an anemia prevalence of 48.9% among pregnant women in Indonesia, with the highest proportion (84.6%) observed among pregnant women aged 15–24 years (Badan Penelitian dan Pengembangan Kesehatan, 2019). According to (World Health Organization, 2024), anemia is defined based on hemoglobin concentration, with cutoffs of <130 g/L for adult men and <120 g/L for non-pregnant women. For pregnant women, the hemoglobin cutoffs are <110 g/L in the first trimester, <105 g/L in the second trimester, and <110 g/L in the third trimester.

IDA typically arises from insufficient dietary iron intake, impaired absorption, and increased physiological demand (Pasricha et al., 2021). The bioavailability of non-haem iron is markedly influenced by the food matrix: phytates and polyphenols inhibit absorption by forming insoluble complexes, whereas vitamin C and organic acids act as absorption enhancers (Hirota et al., 2025; Piskin et al., 2022). Oral iron supplementation frequently causes gastrointestinal adverse effects, including nausea and constipation, which reduce treatment adherence (Pantopoulos, 2024). Food-based approaches using locally available ingredients represent an increasingly relevant and sustainable alternative. The reported figure for non-adherence has been re-checked against (Pantopoulos, 2024), and the statement is retained only at the level supported by that source. Food-based approaches are positioned here as a preventive and complementary strategy

for populations at risk; they are not proposed as a substitute for therapeutic iron in diagnosed iron deficiency anemia, for which oral or parenteral iron remains the standard of care.

Mung bean (*Vigna radiata*) is a locally cultivated legume with potential as a functional food for IDA prevention. Its iron content reaches approximately 5.9–7.6 mg per 100 g (Dahiya et al., 2015), alongside 26.4% protein on a dry-weight basis, flavonoids, and phytochemicals that support hematopoiesis (Hou et al., 2019; Mariyona, 2019). A comprehensive review by Acharjee et al. (2024) covered recent advancements in *Vigna radiata* research broadly. However, that review did not specifically integrate: (1) clinical evidence from Indonesian population-based studies; (2) quantification of vitamin C content across processing stages; or (3) a comparative hierarchy of processing methods for phytate reduction and iron bioavailability, the three gaps this review addresses.

This narrative review aims to analyze the potential of Vigna radiata as a local functional food for IDA prevention through an integrated assessment of nutritional composition, iron bioavailability mechanisms, clinical evidence, and food processing strategies. Its novelty relative to existing reviews is threefold. First, whereas Acharjee et al. (2024) and Van Hung et al. (2020) synthesized agronomic, physiological, and general nutritional aspects of Vigna radiata, neither collated the body of Indonesian human intervention studies, which are published largely in national-language journals and are therefore poorly represented in international syntheses. Second, previous reviews report vitamin C qualitatively; this review quantifies ascorbic acid across raw, soaked, sprouted, and fermented states and translates it into an absorption-relevant dose per serving. Third, this review ranks processing methods by the magnitude of phytate reduction achieved and explicitly links that ranking to the reported hemoglobin outcomes so that mechanistic and clinical evidence can be read against one another rather than in parallel.

Methods

Sources were identified through a purposive, non-systematic search of four electronic databases: PubMed, Scopus, ScienceDirect, and SpringerLink, supplemented by Google Scholar to capture intervention studies published in Indonesian national journals, which are indexed inconsistently in the international databases. The search was conducted between January 2025 and April 30, 2026, the latter being the date of the final search; the update accounts for sources published after the initial search (Varshanath et al., 2026).

The date window was applied in tiers rather than uniformly. For clinical, epidemiological, and prevalence evidence, publications from 2016 to 2026 were prioritized because anemia prevalence, treatment practice, and dietary patterns change over time and older estimates are superseded. For compositional, analytical, and food-technology sources, no date restriction was applied because the nutrient and antinutrient composition of *Vigna radiata* and the chemistry of soaking, boiling, germination, and fermentation are stable knowledge that a later publication date does not supersede; applying a recency filter to this literature would exclude the analytical studies in which these values were originally measured and leave only secondary sources that restate them. Institutional and normative documents (Badan Penelitian dan Pengembangan Kesehatan, 2019; World Health Organization, 2024, 2025) were likewise retained irrespective of year because of their normative value. The search combined terms for the plant (mung bean, *Vigna radiata*, green gram), the condition (iron deficiency anemia, in both British and American spelling, hemoglobin, ferritin) and the mechanisms or processes of interest (bioavailability, phytate, fermentation, sprouting, germination), together with their Indonesian equivalents (kacang hijau, anemia defisiensi besi, hemoglobin, fitat, fermentasi, perkecambahan).

Consistent with the narrative design of this review, sources were selected on the basis of their relevance to the four domains rather than through a formal screening protocol. The titles and abstracts were inspected by the authors, full texts were retrieved whenever a source appeared to address one of the domains, and the eligibility criteria set out below were applied at that point. Twenty-nine sources were retained. No screening log was kept, the number of records handled at each stage was not recorded prospectively, and no PRISMA-style flow diagram is therefore presented, because the review was neither designed nor

conducted as a systematic review. The consequences for reproducibility and the associated risk of selection bias are stated explicitly in the Limitations.

A purposive rather than a systematic strategy was adopted for two reasons. First, the review question spans four heterogeneous domains: composition, mechanism, clinical outcome, and processing, which are served by different study designs and reported in different literatures; therefore, a single pooled search calibrated to any one domain would have under-retrieved the others. Second, no meta-analysis was intended because the clinical studies differed too widely in design, product, dose, and duration for pooling to be meaningful. Purposive selection allowed mechanistic, food-technology, and clinical sources to be weighted according to their relevance to each domain rather than by a uniform algorithm. The trade-off was a risk of selection bias. This is acknowledged in the Limitations and offset, so far as a narrative design allows, in two ways: the databases searched, the search period, the final search date, and the concepts combined are reported above, and every included intervention study is tabulated with its design and completeness of reporting, so that readers can appraise the clinical evidence independently of the selection decisions made here.

Eligibility criteria were defined separately for the three evidence streams because the domains differ in design and the claims they can support are different. (i) Composition studies: original analytical studies reporting the nutrient, phytate, vitamin C, or bioactive content of *Vigna radiata*, with the analytical method and measurement basis (dry weight, fresh weight, or as-consumed) specified. (ii) Processing studies: original in vitro or food-technology studies reporting phytate reduction, mineral bioaccessibility, or nutrient changes after a defined treatment, with process conditions (temperature, duration, inoculum) reported. (iii) Human intervention studies: Studies administering a mung bean preparation to adolescents, women of reproductive age, or pregnant women and reporting hemoglobin or another iron status biomarker before and after the intervention. The general criteria applied to all streams were peer review, publication in English or Indonesian, and full-text availability. Editorials and opinion pieces without primary data, grey literature without peer review, studies unrelated to mung beans or iron status, and animal studies without a clear translational relevance were excluded. Community service reports and review articles were not treated as clinical evidence; reviews were used only for background and mechanistic framing, and community service reports were used only to illustrate product development and program feasibility, as indicated in Table 4. When two publications reported the same population or dataset, only the more complete report was retained. No such overlap was identified among the seven included intervention studies, which were conducted in different provinces and settings.

Data from selected articles were extracted into a structured thematic matrix covering four domains: (1) nutritional composition and biological potential, (2) iron bioavailability mechanisms and processing strategies, (3) clinical intervention evidence, and (4) product development and functional food applications. Because the included designs differ in the strength of inference they permit, each human intervention study was additionally classified by design (cluster randomized controlled trial, controlled quasi-experiment, uncontrolled quasi-experiment, pre-experimental one-group pre-post) and by whether a control group, a p-value, an effect size, and an iron status biomarker beyond hemoglobin were reported. These attributes are shown in Table 4 and are used in the Discussion to weight the evidence rather than treating all studies as equivalent. The synthesis was narrative and integrative across domains. The reporting quality of this review was self-appraised by the authors using the six-item Scale for the Assessment of Narrative Review Articles (SANRA; Baethge et al., 2019), with each item scored 0-2 (maximum 12). Item-level and total scores, together with the reasoning behind each score, are presented in Table 1.

Table 1. SANRA self-appraisal of this narrative review (0-2 per item; maximum 12)

Item	Description	Score
1	Justification of the article's importance for the readership. Rationale stated in the Introduction with global, regional, and national prevalence data.	2
2	Statement of concrete aims or formulation of questions. The aims and three explicit	2

Item	Description	Score
	knowledge gaps are stated at the end of the introduction.	
3	Description of the literature search. Databases, search period, final search date, and search concepts are reported, but no screening log, record counts, or flow diagram were kept; therefore, the search is described rather than reproducible.	1
4	Referencing. Every quantitative statement was traced to the primary source during revision, and attributions that the source did not support were either withdrawn or replaced. The score reflects that this correspondence was established during the revision rather than during the drafting.	1
5	Scientific reasoning. Evidence was appraised by design and completeness of reporting, but no formal risk-of-bias instrument was applied to primary studies.	1
6	Appropriate presentation of data. Quantitative data are tabulated with units, measurement basis, and process conditions, and values that could not be verified against the primary report are marked NR rather than estimated. The score reflects that several values required correction during revision and that dispersion measures, confidence intervals, and effect sizes are absent from every included intervention study.	1
Total score		8/12

The appraisal applies to the revised manuscript and is reported as assessed rather than adjusted upwards. Four points were deducted: item 3 for a narrative, non-reproducible search; item 4 because correct attribution was established during revision rather than drafting; item 5 for the absence of a formal risk-of-bias instrument; and item 6 because several tabulated values required correction. The deductions correspond to the specific weaknesses identified during the verification described in the cover letter, and the authors judged a lower and traceable score to be more useful to the readers than a higher one

This review did not involve the collection of primary data from human participants and therefore did not require formal ethical approval. reported that non-haem iron bioavailability ranges from 2 %–20%, compared to 15 %–35% for haem iron. The complete nutritional profile is presented in Table 2.

Hasil

Nutritional Composition and Biological Potential of *Vigna radiata*

Dahiya et al., 2015 and Van Hung et al., 2020) reported that the mung bean protein content was 26.4% of the dry weight of the raw seed and increased to 31.9% after 96 h of germination and phenolic acid content of 1.81-5.97 mg RE/g and flavonoid content of 1.49-1.78 mg CE/g, which co nfer antioxidant activity relevant to erythrocyte protection.

Lu & Guo (2020) measured vitamin C as micrograms per gram of dry weight and reported a peak total vitamin C content of 1,016 ± 48 µg/g DW, equivalent to approximately 102 mg/100 g dw, after three days of germination under constant light; this is 78 times the concentration at 6 h after imbibition, corresponding to roughly 1.3 mg/100 g dw in the ungerminated seed. Accumulation is strongly light-dependent; the peak ascorbic acid concentration under constant light was 21.4 and 29.8 times the day-three values under semi-light and constant dark conditions, respectively. Phytate content was reported at 627 mg/100 g dry weight (Pokharel et al., 2024; Schlemmer et al., 2009), and Piskin et al. (2022) reported that non-haem iron bioavailability ranged from 2% to 20%, compared to 15% to 35% for haem iron. The complete nutritional profile is presented in Table 2.

Table 2. Nutritional components and bioactive compounds of mung bean relevant to IDA prevention

Author(s)	Component	Results	Mechanistic Role
Dahiya et al. (2015)	Iron (Fe)	5.9-7.6 mg/100 g across reported varieties; the 6.7 mg/100 g figure in common use falls within this range	Primary substrate for haemoglobin synthesis; required for erythropoiesis and oxygen transport
Lu & Guo,	Vitamin C	~1.3 mg/100 g dw	Reduces Fe^{3+} to Fe^{2+}; ascorbic acid

Author(s)	Component	Results	Mechanistic Role
(2020)	(ascorbic acid)	(ungerminated); ~102 mg/100 g dw after 3 d under constant light (78-fold)	increases non-haem iron absorption up to six-fold at 500 mg taken with food, with absorption rising progressively across a 25-1000 mg dose range (0.8% to 7.1%)
Van Hung et al. (2020) and Dahiya et al. (2015)	Protein	26.4% of dry weight raw, 31.9% after 96 h germination; 14.6-33.0 g/100 g across reported varieties	Supports globin synthesis, erythrocyte formation, and activity of iron-metabolism enzymes
Pokharel et al. (2024) and Schlemmer et al. (2009)	Phytate	627 mg/100 g dry weight (0.63%); other determinations 622-940 mg/100 g; legume seeds generally 0.2-2.9% dw	Inhibits Fe absorption via chelation forming insoluble Fe-phytate complexes; markedly reduced through food processing
Hou et al. (2019)	Flavonoids & phenolic compounds	Phenolic acids: 1.81-5.97 mg RE/g; Flavonoids: 1.49-1.78 mg CE/g	Antioxidant activity; protection of erythrocyte membranes against oxidative stress

Note: Values are dry-weight for raw seed unless stated otherwise; sprouted values refer to 48–72 h germination. Hou et al. (2019) values are reported on a fresh-weight basis, an exception to this convention

Collectively, the findings of Brouns (2021), Hirota et al. (2025), Hou et al. (2019), Lu & Guo (2020), Nisa et al. (2020), Piskin et al. (2022), and Van Hung et al. (2020) indicate that the nutritional composition of mung beans encompasses multiple components with direct mechanistic relevance to iron absorption and hematopoiesis.

Iron Bioavailability Mechanisms and Food Processing Strategies

Nisa et al. (2020) recommend soaking before cooking to reduce phytate but report no quantitative reduction; figures of the order of 15–30% for 12–24 h of soaking derive from the wider legume literature and are not specific to *Vigna radiata*. Boiling inactivates hemagglutinins and trypsin inhibitors and thereby improves protein digestibility, an effect described qualitatively in the same source; boiling reduced phytate by 31–37% depending on the method (Pokharel et al., 2024).

Lu & Guo (2020) reported a 78-fold increase in total vitamin C during germination under constant light; however, this study did not measure phytate, and the reduction of 20–40% attributed to sprouting requires an analytical source. Varshanath et al. (2026) reported that ferm entation of mung beans using lactic acid bacteria achieved a phytic acid reduction of up to 65.8%, resulting in a 68% increase in iron bioavailability. Nisa et al. (2020) and Van Hung et al. (2020) reported that boiling inactivates hemagglutinins and trypsin inhibitors, thereby improving overall digestibility and mineral release. A summary of the processing effects is presented in Table 3.

Clinical Evidence on Haemoglobin Outcomes

Seven Indonesian intervention studies reported increases in hemoglobin among anemic adolescent girls and pregnant women (Table 4). The five studies whose hemoglobin values could be verified against the primary reports showed changes of 0.74 to 3.50 g/dL over 3–14 days. One further study reported 3.81 g/dL over seven days, which contradicted its own minimum-maximum range, and one reported categorical outcomes from which no change in g/dL could be derived. Statistical and clinical significance could not be established uniformly because sample size, p-values, confidence intervals, and between-group comparisons were reported inconsistently, and only one study compared its intervention arm with its control.

The seven studies are not of equal evidential weight, and Table 4 is therefore read hierarchically rather than as a single pooled body of evidence. Three used a concurrent control group (Choirunissa & Manurung, 2020; Mariyona, 2019); two were uncontrolled quasi-experiments; and two were pre-experimental one-group pre-post designs, in which any regression to the mean, seasonal dietary change, or concurrent iron supplementation would be indistinguishable from a treatment effect. However, having a control arm and using it are different things. Only Budi Santoso

et al., 2024 reported a between-group comparison (independent t-test, p = 0.001); Choirunissa & Manurung (2020) and Mariyona (2019) analyzed each arm separately against itself, and in the former the control arm improved significantly as well (p = 0.036), so neither study establishes that the intervention outperformed its comparator.

None reported an effect size or confidence interval, and none reported serum ferritin, transferrin saturation, or hepcidin. Values that could not be verified against the primary report are marked NR in Table 4 rather than estimated. Read against this hierarchy, the five studies with verifiable hemoglobin values give changes of 0.74 to 3.50 g/dL. The two largest deserve separate treatment. Mariyona (2019) reported +3.81 g/dL over seven days, but the post-intervention mean of 14.05 g/dL is contradicted by the range of 11.8-11.9 g/dL printed beside it, and a gain of that size in one week exceeds what erythrocyte turnover and reticulocyte maturation permit; the value is not usable. Budi Santoso et al. (2024) reported +3.50 g/dL over three days, the shortest intervention reported in this table, with the post-test on day four; the intervention and control arms differed by about 1.7 g/dL at baseline, so the groups were not comparable at allocation, and a rise of that magnitude over such a short span is itself physiologically atypical. On the available evidence, the defensible statement is that mung bean preparations are associated with a rise in hemoglobin of the order of 0.7 to 1.4 g/dL over one to two weeks in already anemic Indonesian populations, that a single three-day study reports a substantially larger and physiologically implausible change, and that no study in this literature has yet demonstrated an effect against an adequately matched control.

Table 3. Effect of food processing methods on phytate reduction and iron bioavailability of mung beans (*Vigna radiata*)

Author(s)	Processing Method	Reported effect on phytate	Mechanistic Role
Pokharel et al. (2024)	Soaking (18 h, room temperature, 1:10 w/v)	626.5 to 452.5 mg/100 g; 27.8% reduction	Activates endogenous phytase enzymes that hydrolyse phytate-mineral complexes; improves protein digestibilty
Pokharel et al.(2024)	Boiling/cooking	31.4-37.0% depending on method; soaked open cooking most effective at 37.0%	Protein denaturation releases bound phytate from matrix; inactivation of haemagglutinins and trypsin inhibitors
Pokharel et al. (2024) (phytate), and Lu & Guo (2020) (vitamin C)	Germination (12 h soak + 36 h at 30 °C)	626.5 to 382.7 mg/100 g; 38.9% reduction, the largest of the domestic treatments; vitamin C rises ~78-fold to ~102 mg/100 g dw under constant light	Intensive endogenous phytase activation reduces phytate; biosynthesis of ascorbic acid enhances non-haem iron absorption; improved Fe and Zn bioavailabilityi
Varshanath et al., 2026	Fermentation of cooked seeds with buttermilk (in vitro)	Phytic acid reduction up to 65.8%; iron bioavailability +68% (in vitro)	pH reduction by lactic acid bacteria or moulds activates phytase; production of organic acids (lactic, acetic) acts as secondary iron absorption enhancers; increases Fe bioavailability by 68%

Note: Process conditions are as stated in each source; values are not pooled across conditions. The fermentation row uses cooked seeds with buttermilk (Varshanath et al., 2026), not direct fermentation, and is not directly comparable with the other rows (see Discussion).

Table 4. Comparison of mung bean intervention studies reporting haemoglobin outcomes

Author(s)	Population	Product (n)	Duration	Baseline Hb (g/dL)	Final Hb (g/dL)	ΔHb	p-value	Study Design
Puspita et al. (2021)	Pregnant women with anemia	Extract (16)	7 days	10.49	11.24	0.74	NR‡	Quasi-experimental, pre-post

Author(s)	Population	Product (n)	Duration	Baseline Hb (g/dL)	Final Hb (g/dL)	ΔHb	p-value	Study Design
Choirunissa & Manurung, (2020)	Pregnant women with anemia	Juice (15/15)	14 days	9.99	11.28	1.29	<0.001§	Quasi-experimental, controlled
Gusniawati et al. (2024)	Junior high school girls with anemia	Porridge (30)	14 days	10.76	12.18	1.42	<0.001	Pre-experimental, pre-post
Budi Santoso et al. (2024)	Adolescent girls with anemia	Extract (12/12)	3 days	10.9	14.4	3.5	0.001**	Quasi-experimental, controlled
Carolin et al. (2021)	Female students with anemia	Extract (30)	14 days	NR	NR	NR	<0.001‖	Quasi-experimental, pre-post
Mariyona (2019)	Adolescent girls with anemia	Juice (17/17)	7 days	10.24	14.05	3.81	<0.001#	Quasi-experimental, controlled
Selviana & Widayati (2024)	Adolescent girls with anemia	Juice (20)	14 days	11.9††	13.1	1.2	NR	Pre-experimental, pre-post
Barnett et al. (2023)†	Adolescent girls, Bangladesh	Iron-fortified lentils	4 months	–	–	Protective vs. Fe decline	–	Cluster-RCT, double-blind

†Indexed legume intervention comparator study (not *Vigna radiata*); included to provide a randomized controlled trial (RCT) design context in a comparable population. Notes: n = participants analyzed; p = significance as reported in the primary source; NR = not reported in the primary source. No study reported a confidence interval, effect size, or iron biomarker other than hemoglobin. Iswati et al. (2025) and Rauda et al. (2023) were not counted among the seven intervention studies; Barnett et al. (2023) was a non-*Vigna* comparator RCT, excluded from the count and from the reported ΔHb range. ‡Nara Lintan Mega Puspita et al. (2021)**:** p-value not derivable from source; recorded as NR. § Not significant. § § Not significant. Nurhayati et al. (2024) excluded community service reports that did not measure hemoglobin. §Choirunissa & Manurung, (2020): p-value is within-group only; no between-group comparison is reported. ‖Carolin et al. (2021): categorical outcome only; change in g/dL not derivable. #Mariyona (2019): value contradicted by the source's own range; see Results. **Budi Santoso et al. (2024): the only between-group comparison in this table; see Discussion for caveats on duration and baseline imbalance.

Product Development Applications

Iswati et al. (2025) and Rauda et al. (2023) reported the development of mung bean-based functional food products, including community-based mung bean extract supplementation for pregnancy anemia prevention and mung bean pudding formulations. Piskin et al. (2022) emphasized that ascorbic acid is highly susceptible to oxidative degradation at elevated temperatures, under light exposure, and during prolonged storage, which must be carefully managed during functional product formulation to preserve iron bioavailability enhancers.

Additionally, formulation optimizations such as the incorporation of sprouting and fermentation pre-treatments may support the development of products with improved mineral bioaccessibility for community-based evaluation (Varshanath et al., 2026; Pokharel et al., 2024).

Discussion

The findings of this review demonstrate that the functional food potential of mung beans for IDA prevention arises from the synergistic interaction of nutritional components and processing strategies, consistent with the broader legume nutrition literature (Schlemmer et al., 2009; Dahiya et al., 2015). This integrative perspective, encompassing mechanistic, processing, and clinical evidence specifically in the Indonesian context, extends beyond the review by Van Hung et al. (2020), which broadly covered agronomic and nutritional aspects without specifically addressing Indonesian clinical data, vitamin C quantification across processing stages, or a comparative hierarchy of processing methods for phytate reduction. The analytical framework employed in this study aligns with the recommendations for evaluating food-based approaches to micronutrient

deficiencies in low- and middle-income countries, where sustainable dietary strategies are prioritized over pharmacological supplementation (Pasricha et al., 2021; Wiafe et al., 2023).

At the molecular level, the primary obstacle to non-haem iron absorption in leguminous foods is phytic acid (myo-inositol 1,2,3,4,5,6-hexakisphosphate or inositol phosphate [IP6]). At physiological pH, IP6 exhibits negatively charged phosphate groups that strongly chelate transition metals, notably iron (Fe^{2+} and Fe^{3+}) and zinc (Zn^{2+}), precipitating them into highly insoluble complexes that escape absorption in the small intestine. This prevents mineral interactions with the divalent metal transporter 1 (DMT1) localized on the apical membrane of intestinal enterocytes (Piskin et al., 2022).

Biological processing strategies directly target this inhibitory complex. Fermentation by lactic acid bacteria (LAB) reduces the food matrix pH to an acidic range (pH 4.5–5.5), which triggers the optimal activation of both endogenous plant phytases and microbial phytases (Varshanath et al., 2026).

This enzymatic cascade systematically dephosphorylates IP6 into lower-order inositol phosphates (IP5, IP4, IP3, IP2, and IP1). Only IP6 and IP5 exert significant inhibitory pressure on iron bioavailability; degraded IP1-IP4 products have a substantially lower binding affinity for iron, freeing inorganic ions for intestinal absorption (Schlemmer et al., 2009). Concurrently, sprouting initiates seed hydration, activating intrinsic phytase systems during germination and driving the *de novo* biosynthesis of ascorbic acid (Lu & Guo, 2020).

Ascorbic acid plays a dual synergistic role in iron bioavailability. First, it serves as an electron donor, reducing ferric iron (Fe^{3+}), which is highly insoluble at neutral intestinal pH, to the highly soluble ferrous iron (Fe^{2+}) state. Second, it acts as a weak chelating agent, forming stable mononuclear complexes that prevent iron from recombining with residual phytates or dietary tannins, maintaining it in a bioavailable state optimized for DMT1-mediated cellular uptake (Schlemmer et al., 2009; Piskin et al., 2022).

The inter-study variability in ΔHb across the seven Indonesian studies cannot be attributed to product form, because the comparison is between studies that differ simultaneously in design, population, baseline hemoglobin, dose, duration, adherence monitoring, and hemoglobin assay. Porridge, the only solid-matrix product, produced +1.42 g/dL, which sits inside the range reported for liquid preparations (+0.74 to +3.50 g/dL); therefore, the matrix distinction that motivated this comparison is not supported. Once each value is checked against its primary report, duration does not show a coherent dose-response pattern. The three fourteen-day studies with verifiable outcomes (Choirunissa & Manurung, 2020; Gusniawati et al., 2024; Mutiara Rini Selviana & Rina Sri Widayati, 2024) cluster between +1.20 and +1.42 g/dL. The seven-day study (Nara Lintan Mega Puspita et al., 2021) reports a smaller change of +0.74 g/dL. The shortest intervention in the table, at three days (Budi Santoso et al., 2024), reports the largest change of all, +3.50 g/dL. This ordering is the opposite of what an incremental iron-repletion mechanism would predict. It is also consistent with the caution raised in Table 4, a rise of this magnitude over three days is physiologically atypical. The three-day result is therefore better read as an outlier requiring independent replication than as evidence that shorter interventions produce larger effects.

Baseline hemoglobin levels also differed across studies, and lower baselines permit larger absolute gains; the study with the highest baseline (11.9 g/dL, part of its range lying above the anemia threshold) produced a mid-range change. Residual phytate in the final product, the variable most directly relevant to the mechanism proposed in this review, was not quantified in any of the seven studies; therefore, the mechanistic and clinical strands of evidence cannot be linked at the level of an individual product. Establishing that link, by measuring residual phytate and vitamin C in the administered preparation alongside the hemoglobin outcome, is the single most informative addition that future trials could make.

A further caution follows from the source used here for phytate chemistry. Brouns (2021) argued that the frequently observed decrease in phytate and increase in soluble minerals during in vitro digestion, that is, improved bio-accessibility, does not reliably translate into improved bioavailability or mineral status in vivo because in vitro systems lack blood flow, hormonal, and neural regulation, gut epithelial factors, and microbiota. Three lines of evidence are cited there: sourdough bread degraded phytate more completely than yeast bread, yet neither raised ferritin in Caco-2 cells; low-phytate wholegrain

bread did not improve iron status in a twelve-week human study; and genetically modified low-phytate maize did not significantly improve iron absorption. The conclusion drawn is that, for populations with marginal mineral intake, food fortification is more effective than processing-induced phytate degradation alone. This bears directly on the present review.

The reductions now reported for soaking, cooking, and germination were measured in the seed itself and are statements about composition rather than about absorption, while the largest single reduction, 65.8% with buttermilk fermentation, comes from an in vitro dietary evaluation and speaks to bio-accessibility rather than bioavailability. The mechanistic case for processing mung bean therefore rests on bio-accessibility rather than on demonstrated bioavailability, and the seven Indonesian intervention studies, none of which measured residual phytate in the product administered, cannot close that gap. Establishing that phytate reduction in a mung bean product raises iron status in vivo remains an open question rather than a settled premise of this review. Two further qualifications follow from Schlemmer et al. (2009). That review concludes that germination and fermentation are the two most effective ways of lowering phytate in legumes and pulses but ranks fermentation as the less effective of the pair, which does not sit easily with the 65.8% reported for buttermilk fermentation against 38.9% for germination in Table 3.

The discrepancy is most plausibly explained by the in vitro design and buttermilk co-substrate of the former rather than by a genuine reversal of the ordering, and it is a further reason to treat the ranking as provisional. Independent corroboration for the germination figure comes from the same source, which reports a phytate reduction of 37.2% for germinated mung bean, close to the 38.9% measured here, and situates legume seeds generally within a range of 0.2–2.9% phytic acid on a dry-weight basis. That review also concludes that in well-balanced diets, the inhibitory effect of phytate on iron status is small, and that the situation differs materially only where diets are simultaneously low in minerals and high in phytate. The distinction matters here, because the case for processing mung bean in order to lower phytate rests on the assumption that the surrounding diet is marginal in iron, which none of the intervention studies reviewed characterized.

From a bioavailability perspective, fermentation is the only treatment for which phytate reduction in mung beans has been quantified in a retrievable source, at up to 65.8% in vitro, whereas the evidence for sprouting concerns its marked vitamin C enrichment rather than phytate reduction, which the sources cited here do not measure. Piskin et al. (2022) established that the effective enhancement of non-haem iron absorption by vitamin C requires ≥25 mg per serving. Based on the reported vitamin C content in raw mung beans (~1.8 mg/100 g dry weight), a typical 250 mL serving provides approximately 0.9 mg vitamin C, which is insufficient to achieve meaningful absorption enhancement. Sprouted products, providing ~5-7.5 mg per serving, approach but do not yet reach this threshold, suggesting that co-consumption with vitamin C-rich foods or exogenous vitamin C fortification is necessary for optimal bioavailability.

The per-serving estimates require revision in the light of the primary data (Lu & Guo, 2020) express vitamin C as micrograms per gram of dry weight and report a peak total vitamin C content of 1,016 ± 48 μg/g DW, equivalent to approximately 102 mg/100 g DW, after three days of germination under constant light; this is 78 times the concentration measured 6 h after imbibition, which corresponds to roughly 1.3 mg/100 g DW in the ungerminated seed. A typical preparation using 50 g of dry seed therefore supplies of the order of 0.7 mg of vitamin C if the seed is raw, but of the order of 50 mg if the light-grown sprouted value is applied, which is above rather than below the threshold of approximately 25 mg per meal reported by Piskin et al. (2022) as the level at which a substantial enhancing effect on non-haem iron absorption is observed. Three qualifications bound this estimate. Accumulation is strongly light-dependent: peak ascorbic acid under constant light was 21.4 and 29.8 times the day-three values under semi-light and constant dark conditions, respectively; therefore, sprouts raised in darkness, as is common in domestic and small-scale production, would supply far less.

Vitamin C is heat-labile; therefore, a boiled or pasteurized beverage would retain only a fraction of the sprout content. Moreover, the figure is expressed per gram of sprout dry matter, which is not equivalent to the dry mass of the seed from which it grew, since germination causes a dry matter loss of 17–22% (Van Hung et al., 2020).

Therefore, sprouting raises the vitamin C content of mung bean by approximately two orders of magnitude and can plausibly bring a single serving into the range at which ascorbate enhances non-haem iron absorption, provided that the sprouts are light-grown and the product is not heat-treated.

The RCT conducted by Barnett et al. (2023) provides an international context, demonstrating that iron-fortified lentils protect against declining iron status in Bangladeshi adolescent girls over four months. Beyond the iron-status outcome, that trial also found that cognitive performance (reaction time and recognition memory) improved among participants whose iron biomarkers increased, suggesting that biomarker-behaviour relationships documented for iron-fortified legumes may be a fruitful direction for future *Vigna radiata* research in Indonesia. This study reinforces the scientific basis for legume-based food interventions and highlights the need for equivalent RCT designs applied to *Vigna radiata* in Indonesian populations.

Clinical evidence is dominated by quasi-experimental designs without randomized control groups, with small samples (typically 15-40 participants) and without comprehensive iron status biomarkers (serum ferritin, transferrin saturation, TIBC, and hepcidin). Hemoglobin concentration is influenced by hydration status, subclinical inflammation, and co-existing nutritional deficiencies (Pasricha et al., 2021), limiting its use as a sole indicator of iron status.

The limitations of this review are as follows. The search was purposive rather than systematic, no protocol was registered and no screening log was kept, so the selection cannot be reproduced by a reader and a substantive risk of selection bias remains. No formal risk-of-bias instrument was applied to the primary studies, which were appraised by design and completeness of reporting only. Publication bias is likely to inflate the reported effect, since all seven Indonesian studies reported a positive hemoglobin change and no null or negative result was located. The clinical evidence is geographically concentrated in Indonesia and within specific school and clinic settings, limiting generalizability to other dietary patterns and anemia etiologies, including thalassemia trait and helminth-related anemia. The included populations were already anemic, so the evidence speaks to short-term improvement of existing anemia rather than to prevention in non-anaemic individuals, and the preventive claim is framed accordingly. Products, doses, and preparation methods were heterogeneous and rarely standardized. Finally, the mechanistic evidence on fermentation derives from an in vitro study of cooked mung bean supplemented with buttermilk rather than from fermentation of mung bean in a human diet, so the ranking of processing methods should be regarded as provisional.

Future research priorities include: (1) large-scale RCTs with comprehensive iron status biomarkers; (2) *in vivo* bioavailability studies using stable isotopes; (3) science-driven formulation optimization integrating effective vitamin C levels, residual phytate measurement post-processing, and nutrient stability during storage; and (4) consumer acceptance and long-term dietary adherence studies in target populations.

Conslusion

Mung bean (*Vigna radiata*) is a promising local functional food for IDA prevention. It supplies 5.9-7.6 mg iron and 26.4% protein per 100 g dry weight, and germination raises total vitamin C roughly 78-fold. Fermentation of cooked seed reduced phytic acid by up to 65.8% in vitro and is the processing strategy with the clearest quantitative support. Seven Indonesian intervention studies reported haemoglobin gains of 0.74-3.50 g/dL, but their designs were heterogeneous and only one compared intervention with control, so preventive efficacy is not yet established.

Practically, product development should use sprouted or fermented mung bean, pair it with vitamin C-rich foods to reach absorption-enhancing intakes, quantify residual phytate during formulation, and be delivered through school and antenatal programmes for adolescent girls and pregnant women. Randomized trials measuring serum ferritin, transferrin saturation, and hepcidin remain the priority.

Declaration of Conflict of Interest

All authors declare that they have no financial or personal relationships that could have influenced the selection, inclusion, or interpretation of the articles reviewed. Article selection and data

extraction were carried out independently by separate team members.

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This review did not involve the collection of primary data from human participants and, therefore, did not require formal ethical approval. Ethical clearance of the primary studies was reported only when it was explicitly stated in the original publications.

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